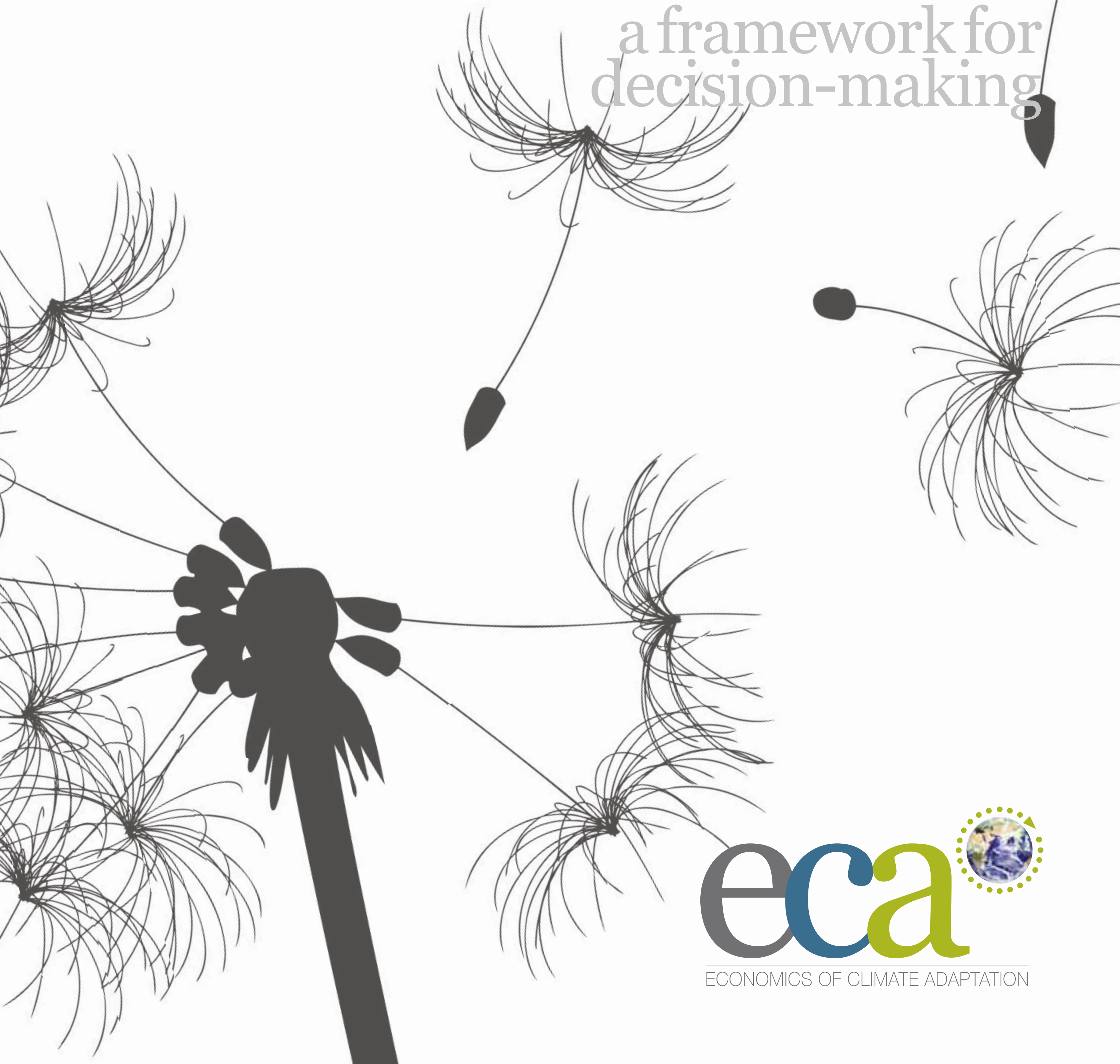
A REPORT OF THE ECONOMICS OF CLIMATE ADAPTATION WORKING GROUP

SHAPING CLIMATE-RESILIENT DEVELOPMENT

a framework for decision-making



ECONOMICS OF CLIMATE ADAPTATION

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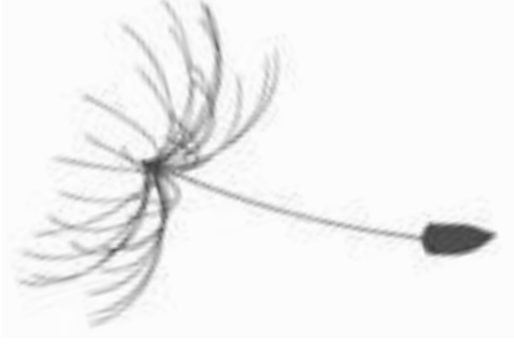

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FOREWORD BY LORD NICHOLAS STERN

In Maharashtra, a large state in central India that is home to nearly 100 million people, agriculture accounts for 60 percent of employment, most of it in small-scale and marginal farming. But the region's agriculture depends on rainfall for much of its water supply, and even a small dip in precipitation can put millions of people's food security at risk. In a drought year, a third of the state's food grain production may be lost, with severe impact on the small-scale farmers– most of whom have no reserves to see them through lean years. Climate change could worsen these losses significantly within a generation. For example, scenario analysis in this report suggests droughts that historically have occurred once every 25 years might now take place as frequently as every 8 years.

Like many other regions, Maharashtra already has a major existing climate adaptation challenge, which climate change is likely to deepen. And like that of many other regions, Maharashtra's adaptation challenge is inextricably linked with its development challenge. Maharashtra's prospects for growth and prosperity are clearly affected by climate change. But if people are well educated, have access to good basic services and can fall back on effective response systems in times of crisis they will be much less vulnerable to climate change. This is why I describe climate change adaptation as essentially *development in a hostile climate*.

This perspective is a key distinguishing feature of the present report. The methodology introduced assesses "total climate risk", from the existing climate as well as from a range of future climate change scenarios, and it quantifies that risk in the context of existing development challenges. Indeed, developed countries, too, have their objectives, challenges and plans which will be profoundly affected by climate change.

Put together by a unique global partnership of practitioners and analysts, the report outlines a step-by-step, evidence-based approach that a decision-maker anywhere can use to understand the economics of climate adaptation in their country or region. The approach has been applied and tested through on-the-ground test cases conducted in a variety of climate-sensitive regions and cities, in both the developed and developing worlds.

These studies have produced some striking findings, which will help country leaders, international institutions and practitioners reframe adaptation as climate-resilient development. We have seen that poor adaptation to current climate already destroys considerable economic value – in the locations studied between 1 and 12 percent of the GDP annually. Impact from climate is not just a future concern, although the scale of possible future climate change could dwarf these losses.

We have also seen that economies are potentially more adaptable than one might think. In the locations studied, between 40 and nearly 100 percent of the expected losses by 2030 – under high climate change scenarios – can be averted through cost-effective adaptation measures that are already known and tested. Better policies and information on climate risk could strengthen incentives for an efficient adaptive response by actors across the economy.

Adaptation, however, is not free. Many of the measures identified require substantial upfront investment. This is why a substantial increase in funding for adaptation to climate change, over and above resources currently committed to development, should be such an important part of the new global deal. But adaptation can be at least partially self-financing. A balanced portfolio of adaptation measures can have a profound and positive impact on economic development. The challenge posed by climate change might lead to action on development that would in any case have been wise.

Consider the example of one of the locations the study assessed, the Mopti region in Mali, which faces the threat of a gradual southward shift of the arid Sahara Desert. The case found that cost-effective measures to bolster cash crops could generate new revenues large enough to not only compensate for Mopti's climate-related losses, but also for those of the entire country. Although this may have environmental and other impacts that require consideration, it is staggering how economic development can offset losses from climate hazards. While responding to risks associated with a shift to a different livelihood model (for example, cash crops versus subsistence farming), the opportunities to better target adaptation funding– and to attract investment for climate-resilient development – are tremendous.

These findings show that our societies have a window of opportunity today: a chance to put in place workable, cost-effective programs that greatly improve their levels of climate adaptation and in so doing boost sustainable development. In the immediate future, the work piloted in this initiative – a powerful starting point – should be scaled up dramatically to develop a much more comprehensive picture of "adaptation as climate-resilient development".

The window will not stay open for long if we fail to take action on the other half of the climate change puzzle – mitigation of carbon emissions – with fierce urgency. If we fail to restrain and reduce emissions sufficiently, quickly and radically, climate change beyond 2030 – for example, in the form of irreversible sea level rise or desertification – could be so disruptive that we will face major losses that cannot be averted.

Even if we do succeed with mitigation, it is by no means a given that our societies will rise to the adaptation challenge. Countries will need to plan for adaptation with much greater rigor, focus, and urgency than has been the case until now – aligning the actions of public, private and NGO stakeholders in concerted effort. Along with this, a greatly increased institutional capacity will be needed in developing countries.

The climate risk to the world's economies and its people is real and present, and its impact on people's lives and livelihoods will worsen rapidly if we do not take action now. The steps to effective adaptation are available and largely affordable. The work of putting them in place will be challenging – but hugely rewarding. We owe it to the most vulnerable people on the planet to combine the best-possible support to strengthen adaptive capacity and get on the pathway to a low-carbon, climate-resilient development. The poorest on the planet cannot bear the majority of climate risk for the rest of us.

Nicholas Stern

Lord Nicholas Stern
Chair | Grantham Research Institute on Climate Change and the Environment | London School of Economics

EXECUTIVE SUMMARY

Many national and local economies are already vulnerable to climate events, in the form of floods, droughts, heat waves, and tropical storms. Global warming, which could see the Earth's surface temperature rise by 2.5-5.9 degrees Celsius by the end of the century compared to pre-industrial levels[1], could greatly heighten this vulnerability, triggering more frequent and severe weather disasters, shifts in rainfall patterns and climate zones, and a rise in sea levels.

Climate adaptation is thus an urgent priority for the custodians of national and local economies, such as finance ministers and mayors. Such decision-makers ask: What is the potential climate-related loss to our economies and societies over the coming decades? How much of that loss can we avert, with what measures? What investment will be required to fund those measures – and will the benefits of that investment outweigh the costs?

The aim of this report is to provide decision-makers with a systematic way of answering these questions. Focusing specifically on the economic aspects of adaptation, it outlines a fact-based risk management approach that national and local leaders can use to understand the impact of climate on their economies – and identify actions to minimize that impact at the lowest cost to society.

The report is based on the initial findings of a study by the Economics of Climate Adaptation Working Group, a partnership between the Global Environment Facility, McKinsey & Company, Swiss Re, the Rockefeller Foundation, ClimateWorks Foundation, the European Commission, and Standard Chartered Bank.

1. DESIGNING A SYSTEMATIC APPROACH TO CLIMATE ADAPTATION

Over the past 50 years, severe weather disasters have caused some 800,000 deaths and over a trillion dollars in economic loss – and in the present decade the damage wrought by such disasters has reached record levels. Economies in many parts of the world are already susceptible to significant disruption from today's climate – and continued economic growth could put even more value at risk. Climate change could cause significant incremental loss, even within the next 20 years. However, knowledge about future climate – particularly the local impacts of global climate change trends – is incomplete. Decision-makers will have no option but to make policy and investment choices under uncertainty.

As a practical contribution to the knowledge base on climate risk and adaptation, the Working Group has developed a quantitative decision-making framework built around two sets of tools.

- First, the framework provides tools to quantify a location's "total climate risk". Included in this quantification is an assessment of the expected annual loss to the location's economy from existing climate patterns; a projection of the extent to which future economic growth will put greater value at risk; and finally, an assessment of the incremental loss that could occur over a twenty-year period under a range of climate change scenarios based on the latest scientific knowledge.

- Second, the framework uses cost-benefit discipline to evaluate a selection of feasible and applicable measures to adapt to the expected risk – spanning infrastructural, technological, behavioral and financial solutions. The output of this cost-benefit exercise provides one key input – along with policy, capacity, and other considerations – for a country, region or city assembling a comprehensive adaptation strategy. Because any such strategy will need to be closely integrated with the location's broader economic development choices, many of the measures evaluated will be economic development steps.

The Working Group developed a detailed methodology to underpin this framework, and applied it in eight on-the-ground test cases in China, Guyana, India, Mali, Samoa, Tanzania, the UK, and the US, conducted in partnership with local governments and stakeholders. The cases focused on selected climate-sensitive regions and cities in each of these countries, and tested the methodology against a sample of climate hazards, economic impacts, and development stages.

The assessments undertaken in these test cases were built on broad metrics of climate-related economic loss, such as GDP, asset value, and agricultural production, and in most cases did not attempt to calculate the additional social and environmental costs of climate impacts. In selected cases, however, the methodology was extended to incorporate human costs – including the impacts of climate risk on health, homes and livelihoods – as well as to the losses facing particular economic sectors such as power generation. The cases did not calculate losses beyond 2030, nor make national policy recommendations.

2. TOWARDS SOLUTIONS: FINDINGS FROM THE TEST CASES

There were four overarching findings from the test cases.

The first is that, despite much uncertainty about the possible effects of global warming on local weather patterns, society knows enough to build plausible scenarios on which to base decision-making. This is true even in developing countries, where historical longitudinal climate data may be limited. Using such scenarios helps decision-makers identify adaptation measures that would be useful against a range of climate change outcomes.

The second finding is a sobering one: significant economic value is at risk. If current development trends continue to 2030, the locations studied will lose between 1 and 12 percent of GDP as a result of existing climate patterns, with low income populations such as small-scale farmers in India and Mali losing an even greater proportion of their income. Within the next 20 years, climate change could worsen this picture significantly: in the locations studied, a scenario of high climate change would increase today's climate-related losses by up to 200 percent as soon as 2030.

Thirdly, however, the cases found that a portfolio of cost-effective measures can be put together to address a large part of the identified risk. In principle, between 40 and 68 percent of the loss expected to 2030 in the case locations – under severe climate change scenarios – could be averted through adaptation measures whose economic benefits outweigh their costs - with even higher levels of prevention possible in highly targeted geographies. These measures include infrastructure improvements, such as strengthening buildings against storms or constructing reservoirs and wells to combat drought; technological measures, such as improved fertilizer use; systemic or behavioral initiatives, such as →

awareness campaigns; and disaster relief and emergency response programs. Risk transfer or insurance measures also play a key role in addressing low-frequency, high-severity weather events such as once-in-100 year floods. However, in most cases there remains a proportion of climate-related risk that cannot be averted through known adaptation measures – underlining the fact that adaptation, no matter how well designed, cannot be a substitute for action to reduce carbon emissions and slow the rate of global warming.

Finally, the cases reinforced the view that adaptation measures are in many cases also effective steps to strengthen economic development – especially in developing countries. In Mali, for example, the implementation of climate-resilient agricultural development could potentially bring in billions of dollars a year in additional revenue. Measures with demonstrated net economic benefit are also more likely to attract investment – and trigger valuable new innovations and partnerships. Indeed, well-targeted, early investment to improve climate resilience – whether in infrastructure development, technology advances, capacity improvement, shifts in systems and behaviors, or risk transfer measures – is likely to be cheaper and more effective for the world community than complex disaster relief efforts after the event.

The specific outputs of each of the test cases, underpinning these findings, are summarized in Appendix 1 of the report.

3. TAKING CLIMATE-RESILIENT DEVELOPMENT FORWARD

The framework presented in this report can help societies better understand the climate risk to their economies – and provide vital input into impactful, cost-effective adaptation strategies that boost overall economic development.

The initial application of the framework to the eight local test cases generated several important lessons on how decision-makers can best assess and address the climate risk facing their economies and societies – not least of which is the insight that a common risk framework does indeed apply across hugely diverse locations, climate risks, and economic impacts. The implication for decision-makers is that it is possible to undertake a focused, solutions-oriented climate risk assessment in a short space of time. ➔

A second key lesson is that, even in locations where climate and economic data is sparse – as is often the case in least developed countries – it is possible to develop a robust climate loss model and quantify the economic costs and benefits of a wide range of adaptation measures. A systematic framework, combined with in-depth engagement with local experts, officials and populations, can provide a strong basis for decision-making.

Further, the test cases emphasized differences in the climate risk profiles of individual regions and cities – and even the individual districts and suburbs within them. An effective climate risk assessment should be built on multiple local assessments – not an extrapolation of a few local assessments to the national level. Equally, adaptation measures should be evaluated and selected based on local applicability.

The test cases did not analyze the steps that would be required to implement the identified adaptation measures in the locations studied. However, the following steps would be key to implementing a comprehensive climate-resilient development strategy at the national or local level:

- Create an inclusive national or local effort. This would ideally be an official process led by a senior government decision-maker, with significant engagement from the private sector, NGOs and academics
- Define current and target penetration of the priority measures identified
- Address existing obstacles to development implementation, such as policy frameworks, institutional capability, and organization
- Encourage sufficient funding from the international community – for example, technical skills, institutional capacity-building, policy and planning, and knowledge dissemination
- Recognize and mobilize different roles for each stakeholder, including governments, NGOs, the private and informal sectors, communities, and individuals.

While this report is by no means the complete answer to the complex problem of economic development in the face of increased climate risk, it is intended as a practical contribution to shaping climate-resilient development paths at the country and local level. The framework described here should assist decision-makers in allocating public and private sector funding to the most effective, resilience-building adaptation measures that encourage sustainable development❍

INTRODUCTION

This report has an important yet narrow objective: to present a practical framework that national and local decision-makers can use to quantify the risk that climate poses to their economies, and to minimize the cost of adapting to that risk.

The specifically defined and focused set of questions addressed by the report is of vital importance for the finance minister or mayor who – with limited time, information, and resources – must make decisions on how best to protect his or her economy from climate risk. For the custodian of a national or local economy, it is crucial to understand what value, which people, assets and sectors are at risk, both from historic climate patterns and from the incremental threat of possible climate change. Just as importantly, these decision-makers need a robust yet rapid way to identify the adaptation measures required in the near-term to avert the greatest possible loss at the lowest possible cost to society.

The report addresses only a small corner of the broader topic of climate adaptation. It does not attempt to put a global price tag on adaptation. It does not address many of the non-economic impacts of climate change that decision-makers must consider, such as on ecosystems. And while the report provides decision-makers with a toolkit to assess their local climate risk and identify a cost-effective set of adaptation measures, it does not provide the answer on how to tackle the institutional and capacity issues that may well stand in the way of implementing those measures.

To date, decision-makers have lacked a full set of quantitative, bottom-up tools to conduct these assessments. Some existing studies have highlighted the lack of a systematic way of estimating climate risk[2], while the Intergovernmental Panel on Climate Change (IPCC) has noted that "many adaptations can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking"[3]. Indeed, extensive work has been done to identify effective adaptation measures, for example through the National Adaptation Programs of Action (NAPAs) conducted in over 40 least developed countries – but to date there has been no systematic approach to calculate and compare the costs and economic benefits of these measures that uses bottom-up estimates.

The Economics of Climate Adaptation Working Group, the author of this report, was formed in September 2008 to help build out this knowledge base.

The Working Group focused on developing a robust, practical framework to allow national and local decision-makers to assess the "total climate risk" facing their economies, and to minimize the cost of adapting to that risk. We applied proven techniques – hypothesis-driven problem solving, scenario planning, risk quantification and management, cost-benefit analysis and strategic planning – to build an end-to-end approach to drive decision making under uncertainty. We put the framework into practice in a set of initial test cases conducted in eight climate-sensitive regions and cities across China, Guyana, India, Mali, Samoa, Tanzania, the UK, and the US. Our purpose in these local cases was to test the workability of the framework for a range of climate hazards, geographies and economic impacts. It was applied across climate zone shift, drought, flood, storm, and sea-level rise hazards; to highly developed cities as well as to subsistence farming communities in developing countries; and both to purely economic impacts and to the impacts of climate on human life and health. More than 600 different adaptation measures – across infrastructural, technological, behavioral, and risk transfer categories – were evaluated across the locations studied.

Through this diversity of closely focused test cases, we sought also to derive lessons for future, more comprehensive applications of the framework.

Although the test cases represent a small subset of locations and their findings can only be indicative, they offer both sobering and encouraging news for decision-makers. Sobering, considering that as much as 19 percent of GDP is at risk from climate hazards over the next two decades in some of the areas studied – with both historic climate patterns and the additional impacts of

climate change posing significant economic risk. Encouraging, because even in the particularly vulnerable regions selected for the test cases, cost-effective adaptation measures were identified to safeguard much, and in some cases most, of the value at risk – and suggests opportunity to make development choices that considers the climate risk. In many cases, there was a large overlap between these adaptation measures and steps that would in any case promote economic development – for example, improved irrigation techniques in drought-prone agricultural areas. This is consistent with the IPCC's finding that "adaptation measures are seldom undertaken in response to climate change alone".

The implications for decision-makers are clear. The risks to their economies from climate are real and imminent. Action to guard against that risk is in many cases feasible and cost-effective – and often constitutes good economic development practice. It should therefore be a priority for decision-makers both to take early action to assess and address climate risk to their economies, and to overcome barriers to implementing adaptation measures.

This report summarizes the Working Group's efforts to date, aiming to provide practical guidance to national and local decision-makers wishing to strengthen the climate-resilience of their economies. Although the report has drawn on the advice of many leading academic thinkers, it is not intended as an academic research paper, but rather a framework to guide decision-making. The report is structured in three chapters:

- Chapter 1, "Designing a systematic approach to climate adaptation", outlines the threat that climate poses to economic development, highlights the difficulties that decision-makers face in shaping effective strategies to address the risk, and sets out the approach developed by the Working Group to address these challenges.

- Chapter 2, "Towards solutions: findings from the test cases", profiles the major insights from across the cases and discusses their implications for decision-making at the national and local levels.

- Chapter 3, "Taking climate-resilient development forward", discusses how countries, regions and cities can use the approach outlined in this report to undertake a focused, solution-oriented climate risk assessment and identify a portfolio of costed, effective adaptation measures. The chapter also outlines some of the key steps to implementation of such a portfolio.

The Appendices contains a summary of each of the eight test cases, as well as step-by-step Methodology Guide for national and local decision-makers seeking to apply the framework in their own jurisdictions ❍

CHAPTER 1: A SYSTEMATIC APPROACH TO CLIMATE ADAPTATION

The risk from climate – today and in the future | Tools to support decision-making | The Economics of Climate Adaptation Working Group – our contribution | A framework to assess and manage total climate risk | Overview of the test cases | Key analyses

The human and economic devastation wrought by recent weather disasters – including hurricanes, floods, droughts and heat waves – has heightened the concern of many decision-makers about their economies' vulnerability to natural forces. They are also aware that two powerful trends may well increase this vulnerability in coming decades. One is continued economic development, which is likely to put more people and greater value in the path of destructive weather. The other is global warming, which many scientists believe is already changing rainfall patterns, increasing the frequency and severity of storms and droughts, and causing gradual shifts in sea level and climate zones.

However, it has proved difficult for leaders to translate these concerns into practical, effective action to reduce their region's vulnerability to the overall climate threat, for two main reasons. The first is uncertainty: although the IPCC presents consensus views on climate risks at regional and sometimes even national levels, the application of these views to local concerns can be limited because weather patterns and levels of adaptation to climate vary widely between and within countries. Second, even if there was agreement on the threats ahead – more severe flooding of coastal cities, for example, or damage to agriculture from reduced rainfall – decision-makers face a bewildering array of possible measures to guard against those threats, each with its own costs and benefits – and a set of competing priorities for limited resources.

This chapter sets out the context for this report: the substantial risk posed by climate to economic development paths, and the difficulty decision-makers face in assessing that risk and identifying cost-effective adaptation steps in their own geographies. The chapter then outlines the approach developed by the Economics of Climate Adaptation Working Group in tackling this challenge.

THE RISK FROM CLIMATE – TODAY AND IN THE FUTURE

Over the past 50 years, great weather disasters have caused some 800,000 fatalities and over a trillion dollars in economic loss – and in the present decade the damage wreaked by such disasters has reached record levels. There are all too many examples. Tropical Cyclone Nargis, which struck Myanmar in May 2008, caused widespread flooding in the Irrawaddy Delta, resulting in many thousands of deaths. The floods that inundated many parts of the UK in the summer of 2007 destroyed $8bn in economic value – the largest flood loss in that country's history. Hurricane Katrina, which hit the USA's Gulf Coast in August 2005, led to over 1,000 deaths and caused greater economic loss – some $125bn in total – than any previous weather event. And the European heat wave of 2003 was the continent's largest natural catastrophe in centuries, with more than 35,000 fatalities.

In addition to the vast human suffering that these and other events have caused, the loss to the world's economies from weather disasters is already substantial, with just the insured loss from natural catastrophes ranging between $10bn and $50bn a year over the past decade (Exhibit 1). Decision-makers at national and local levels, in both the public and private sectors, are rightly concerned about the vulnerability of their economies to natural forces. Developing countries and poorer communities, generally the least adapted to the climate[4], are particularly at risk of losing livelihoods. In addition to these examples of dramatic weather events, many populations and economies are struggling with the more gradual impacts of climate change, such as sea level rise and climate zone shifts. For example, sea level rise and its associated effects, including coastal flooding and salinization, pose a threat to the very existence of some Small Island Developing States (SIDS), such as Kiribati and the Maldives, and to the way of life of coastal inhabitants everywhere.

Many economies, then, are susceptible to significant damage from today's climate – even without factoring in the possible future impacts of climate change and the potential growth of populations and asset value in vulnerable locations. Unfortunately, these factors could well heighten the vulnerability of many countries and regions.

Consider the impact of population and economic growth. In 1950 the world was home to 2.5 billion people; by 2009 this figure had reached 6.8 billion. Over the same period, world GDP grew almost tenfold. Population growth is expected to proceed apace, with a global population of around 9 billion projected by 2040;

Major natural catastrophes, 1972–2008

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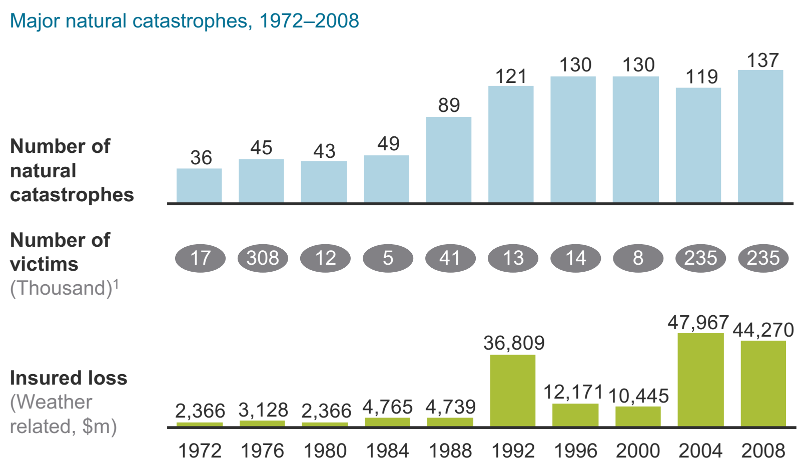
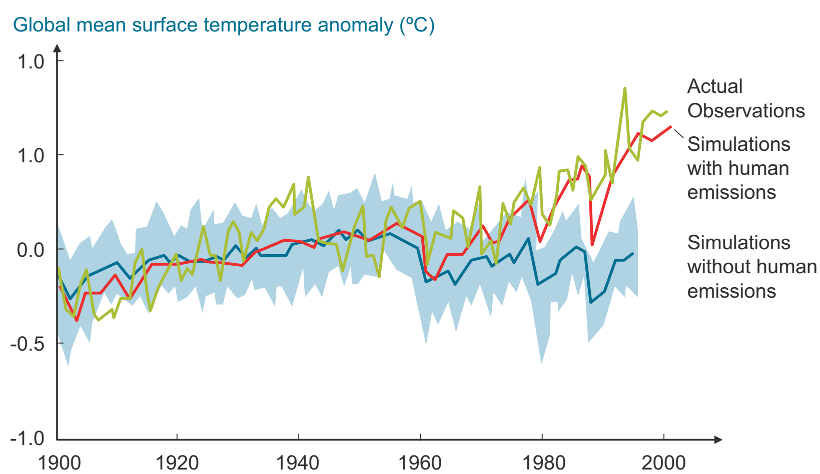


1 Dead and missing

Observations and simulations of global surface temperature

02



800,000

Over the past 50 years, great weather disasters have caused some 800,000 fatalities and over a trillion dollars in economic loss.

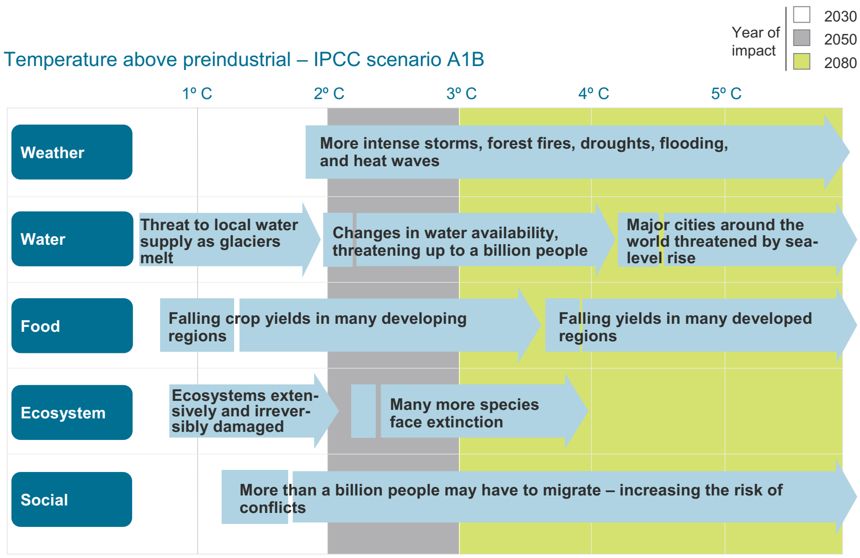
and although world economic growth has slowed during the current downturn, it is projected to return to its path of rapid expansion by 2011.

By multiplying the overall pool of population and economic value, this pattern of growth increases the scale of losses from weather and climate. In many cases it has also heightened humankind's vulnerability to the weather, for example by increasing population and value concentrations in coastal cities, and by degrading natural systems that historically have absorbed some extreme weather. Most of the increase in loss from weather disasters over the past two decades can be attributed to socio-economic factors. As populations and economies continue to grow, the total value – and human life – at risk from climate will increase, too. Depending on the development choices that decision-makers make today, a disproportionate share of the future growth may take place in climate-sensitive areas, and natural resources such as water may become more stretched – thus heightening the vulnerability of societies and their economies.

To this challenging picture, we must add the question of climate change. Most scientists now agree that an increase in human-induced greenhouse gas (GHG) emissions is raising the Earth's surface temperature. For example, data published by the IPCC shows a marked upward trend over the past 50 years in surface temperatures attributable to human emissions (Exhibit 2). In the run-up to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen in December 2009, world leaders will →

03

Possible impact of global warming on different sectors



focus their discussion on securing a global deal to reduce global emissions to the level that most scientists believe is required to slow the rate of warming below dangerous levels. But because the climate system is slow to react to changes in emissions, warming is projected to continue even if a global deal results in emissions being stabilized and reduced. The effort to achieve these targets would itself be a multi-decade journey and climate impacts face societies today.

Global projections suggest that warming could increase both the frequency and severity of disasters such as floods, drought and extreme wind, and trigger major new risks such as a rise in sea levels, with serious consequences for human life and economies – and that the greater the warming, the more serious the possible impacts (Exhibit 3). But how might these global trends translate into impacts at the local level? What are the specific shifts in weather patterns that country and city decision-makers should prepare for?

Although considerable research has been conducted into these questions in many parts of the world, much uncertainty remains about the answers. Our Mali test case provides an extreme illustration of this uncertainty: scientific projections of rainfall over the next 20 years in one key region range from a decrease of 10 percent to an increase of a similar amount[5]. While this degree of variance might be attributed to the Mali case's reliance on general circulation model results – less granular than regional climate model results used in other cases – uncertainty in climate projections is a widely experienced challenge. As one major study acknowledges:

> "*Assessment of impacts is hampered because of uncertainty in climate change projections at the local level (for example, in rainfall, rate of sea level rise and extreme weather events)... Other uncertainties stem from an incomplete knowledge of natural and human system dynamics, and limited knowledge of adaptive capacity, constraints and options.*[6]"

Although science can provide a range of forecasts about the changes in climate that economies may need to adapt to, decision-makers will have to make policy and investment choices under uncertainty, catering for a variety of future climate risk scenarios. As the UK government's *Stern Review* noted:

> "*Effective adaptation will involve decisions that are robust to a range of plausible climate futures and are flexible so they can be modified relatively easily.*[7]"

TOOLS TO SUPPORT DECISION-MAKING

A local decision-maker thus faces the challenging task of understanding and acting on three overlapping factors that together constitute climate risk:

- The threat already posed to society from today's climate
- Development paths that might put greater population and value at risk
- The potentially devastating but still largely uncertain additional risks presented by climate change

Such decision-makers can draw on the wealth of existing research on climate risk and adaptation developed in recent years by governmental, intergovernmental, private, non-profit, and academic organizations.

For example, the IPCC has synthesized the assessments of the possible impact of global warming on a range of sectors and geographies. The UNFCCC has

overseen national programs of action on climate adaptation (NAPAs) for more than 40 least-developed countries, combining scientific research with on-the-ground stakeholder engagement. Pioneering adaptation studies in the 1990s evaluated the vulnerability and adaptive potential – often linked to development levels – of many regions[8]. For example, the U.S. Country Studies Program[9] conducted 49 assessments of countries' vulnerability to climate change, and several of these efforts evaluated climate adaptation options against policy objectives, scoring each adaptation option for its performance in meeting these objectives under different scenarios[10]. The United Nations Development Program (UNDP), through its Adaptation Policy Frameworks, has created a structured approach for scoping and designing adaptation projects. The World Resources Institute (WRI) has examined 135 examples of adaptation policies, projects and initiatives in developing countries. Academic thinkers have developed valuable methodological approaches for tackling adaptation, and detailed case studies to assess the costs of adaptating national infrastructure to climate change[11]. Reinsurance companies have drawn on their claims databases and loss models to map the changing risk profiles of specific hazards and locations.

This knowledge base provides a powerful starting point for assessing and addressing climate risk (see the Bibliography for a full listing of the key existing literature). However, there are some important and widely acknowledged gaps in this knowledge – gaps which the Economics of Climate Adapation Working Group came together to address. For example, the IPCC's fourth assessment report states with high confidence that "many adaptations can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking", and that "the literature on adaptation costs and benefits remain quite limited and fragmented in terms of sectoral and regional coverage"[12].

The Working Group's efforts are aimed at filling two specific gaps identified in existing studies[13]:

- Limits to the quantification of risk: there is no systematic way of estimating climate risk, and no overarching methodology to facilitate comparisons between the risks posed by different hazards and in different geographies
- Lack of decision-support tools: the existing research and policy base does not provide decision-making methodology to address climate risk in a systematic, resource-efficient way

The Working Group's objective, then, has been to provide national and local decision-makers with a systematic approach to assess their societies' vulnerability to climate risk over a multi-decade horizon, evaluate the cost and effectiveness of measures to address that risk, and integrate a portfolio of such measures into their broader economic development agendas. Arming decision-makers with a robust, long-term view of climate risk management is, we believe, critical to ensuring that resources for adaptation are allocated efficiently. Indeed, taking action based on immediate perceived risks in the absence of a broader risk assessment exercise may in fact worsen a society's adaptive capacity. For example, an expensive drought-adaptation program in reaction to three years of drought may be a poor investment if rainfall in the region is expected to increase significantly over the coming decades due to changes in global circulation patterns. →

Likewise, there is the danger that, in the absence of quantitative decision-support tools, perceived immediate climate threats will spur decisions based on misestimates of the value of particular adaptation measures. A series of unconnected, reactive adaptation measures adopted by the public and private sectors may protect individual households or assets, but could fail to address an economy's overall vulnerability. Worse, they might neglect marginal populations already poorly adapted to climate. Some societies may even fail to take any proactive climate adaptation measures, falling back on aid in the wake of disasters – a stance that could put much greater numbers of lives and higher economic value at risk.

THE ECONOMICS OF CLIMATE ADAPTATION WORKING GROUP – OUR CONTRIBUTION

The Economics of Climate Adaptation Working Group was formed in September 2008 under the initiating sponsorship of the Global Environment Facility. (See Box: Expertise of the Economics of Climate Adaptation Working Group.) We set out to develop a practical framework – grounded in robust analysis – that would allow national and local decision-makers to assess the "total climate risk" facing their economies, and to minimize the cost of adapting to that risk through climate-resilient economic development strategies. We sought to enable decision-makers to undertake three important steps:

- Conduct rigorous assessments of the climate risk facing their economies – spanning all significant climate hazards and the full range of possible impacts, from urban infrastructure to agricultural production to human health
- Gain an accurate understanding of the measures available to address those risks, as well as the costs and benefits of those measures
- Prioritize the most effective measures and integrate these into their economic development strategies

The Working Group's intention was to complement existing valuable work to identify adaptation measures and strategies, including the ongoing NAPA process noted above, by providing a quantitative basis for assessing a region's underlying climate risks and a framework for evaluating and comparing the adaptation measures identified.

Having developed the framework, the Working Group then conducted on-the-ground test cases in eight quite different climate-sensitive regions and cities – in China, Guyana, India, Mali, Samoa, Tanzania, the UK, and the US. To test the framework, each case focused on the risk from one or two key climate hazards (such as drought, flood, or sea level rise) to 2030 providing a preliminary quantification of the risk to the locations' economies, and assembling an initial portfolio of cost-effective adaptation measures. Altogether, the test cases considered the risk from 12 different climate hazards, evaluated over 600 local adaptation measures, and quantified the loss abatement potential and costs of a shortlist of more than 150 of the most promising measures.

The test cases were conceived as learning exercises to apply and refine the framework in diverse settings, and each case was conducted rapidly, over an eight-to twelve-week period, often in a context of limited data and considerable uncertainty about future climate patterns and impacts. Accordingly, the results can only be indicative, and not a complete answer to these regions' adaptation challenges. Nonetheless, it was possible even in these limited test cases to create clear indications of the magnitude of the threat that climate poses to regional economies, and of the broad cost of adapting economies to that threat.

The test cases provided lessons learned and validated the framework as a decision-making support tool and provided a useful starting point in quantifying both the climate risk to economies, and the costs and benefits of a wide range of adaptation measures. We should emphasize, though, that this quantification is intended only as a first step in shaping and implementing effective strategies for climate-resilient development. To make practical use of the insights generated by our framework, much additional work will be required from policymakers, engineers, agricultural specialists, geographers and geologists, economists, climate change scientists, and development specialists among others.

The quantitative framework developed by the Working Group is also intended as a contribution to unlocking the resources needed to fund improved climate resilience. This is an important

consideration: although the Copenhagen negotiations are likely to increase international public funding for climate adaptation, the existing range of assessments suggests that the vast majority of the funds required to strengthen climate resilience will have to come from the private sector[14]. Rigorous assessments of climate risk, together with quantification of the costs and benefits of climate-resilient development measures, will highlight new investment opportunities and so should help unlock innovation, public-private partnerships, and investment.

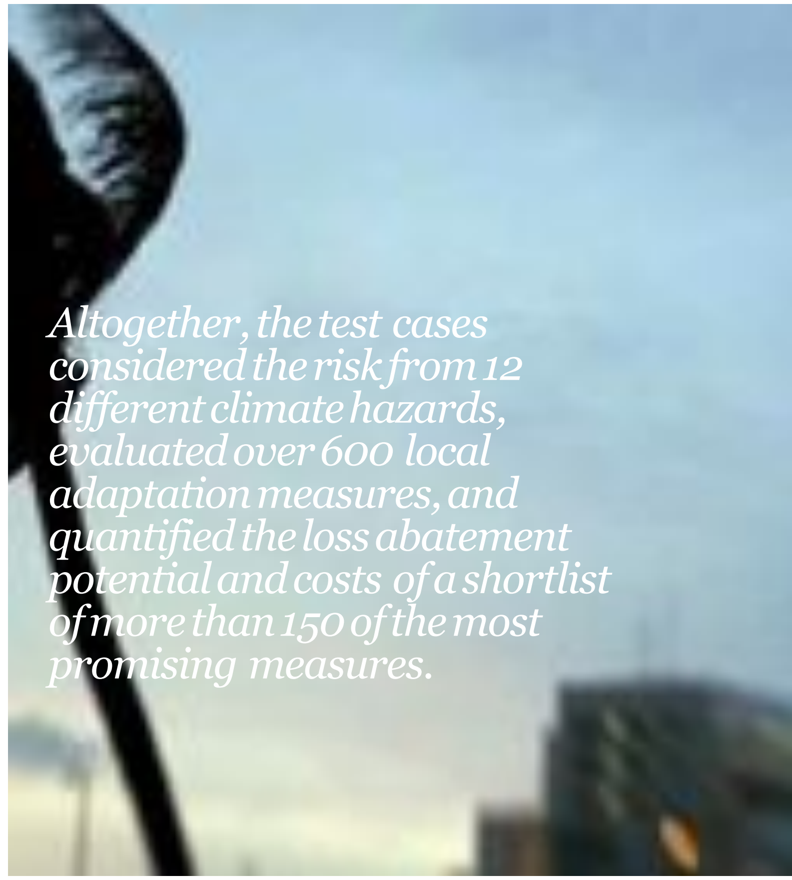
It is worth emphasizing that the Working Group focused its contribution narrowly on developing and testing quantitative tools to assess the economics of adaptation. Our work intentionally did not address the following broader adaptation issues:

- Assessing policy or regulatory choices. We did not seek to assess policy levers such as climate risk screening guidelines, which might make downstream development projects more resilient to climate risks. For national and local decision-makers, policy and regulatory choices can of course be powerful enablers of adaptation, helping to ensure that technical, behavioral, and financial measures are implementated at an optimal scale. A well-developed set of literature covers such policy choices in depth[15]

- Assessing climate science. We did not seek to assess current climate science, drawing instead on the IPCC and other widely accepted academic research as the basis for assessments of current and future climate risk.

- Assessing all climate change impacts. We also did not conduct a complete assessment of all the impacts of climate change on a particular location. For example, none of our test cases assessed the impacts of climate change on ecosystems. Further, we scoped the brief test cases to apply the framework only on one or two significant climate hazards in each location and not a comprehensive set of hazards. The framework was applied to two trend change scenarios – climate zone shift in Mali and sea level rise in Samoa – but we did not evaluate in a single case the combination of event and gradual shifts .

- Calculating the global cost of adaptation. We did not attempt to calculate the global cost of climate adaptation.



Comparing our risk-based expected annual loss numbers to other approaches will be misleading. Current estimates of the global need for adaptation are in the tens of billions of US dollars per annum and significant efforts are underway to size the total costs (see the Methodology Guide in the Appendix for a fuller discussion of these efforts). A significant body of work is already in existence or underway to evaluate the cost of adaptation and required compensation for developing countries impacted by climate change. Furthermore, we did not take on the challenge of estimating the optimal level of investments that will be needed over the next 10-15 years to effectively link mitigation to adaptation: this would have required calculating the cost of adaptation for a range of mitigation outcomes that may take place beyond 2030.

- Testing existing methodological approaches. Although our methodology built on existing tools, we did not attempt to test multiple existing approaches in our work. For example, we did not weigh or distribute the value at risk to emphasize more vulnerable populations We also did not test how to model spontaneous adaptation response or behavior, nor how the portfolio of adaptation investments would change if the timeframe of the test cases were extended beyond 2030. →

EXPERTISE OF THE ECONOMICS OF CLIMATE ADAPTATION WORKING GROUP

The Working Group is comprised of members drawn from multiple disciplines across the private, public and social sectors, who provided the institutional collaboration needed to tackle the challenge of building a quantitative framework to assess the economics of adaptation:

- The initiating sponsorship for the effort came from the **Global Environment Facility** (GEF), a global partnership between 178 countries and many international institutions, private sector institutions, and NGOs

- **Swiss Re**, a leading global reinsurer, was a lead contributor to the research, and brought its natural catastrophe and climate risk assessment knowledge to bear on the challenge of quantifying climate risk

- **McKinsey & Company**, a global management consulting firm with extensive experience working on issues related to climate change, provided overall project management, drove the analytical execution, and contributed to the fact base of this report

- Sponsorship and key guidance was provided by **ClimateWorks**, an international network of foundations focused on achieving low-carbon development; the **European Commission**, which focused on developing a practical methodology to assist adaptation in the most climate vulnerable developing countries; the **Rockefeller Foundation**, which brought its deep experience of building climate resilience in developing countries; and **Standard Chartered Bank**, a global bank with a focus on the emerging markets of Africa, Asia and the Middle East, many of which are among the most exposed to climate risk

The Working Group's efforts were supported by a technical advisory group of leading thinkers and practitioners[17]:

- **Thomas E Downing**
  Director of Stockholm Environment Institute's Oxford office, and Munich Re Foundation Chair in social vulnerability with the United Nations University Institute for Environment and Human Security

- **Samuel Fankhauser**
  Principal Research Fellow at the Grantham Research Institute on Climate Change and the Environment at the London School of Economics

- **Michael Hanemann**
  Professor at the University of California, Berkeley, and Director of the California Climate Change Center

- **Saleemul Huq**
  Head of climate change work at the International Institute for Environment and Development (IIED)

- **Martin Parry**
  A climate scientist at the Grantham Institute, Imperial College London, and co-Chair of the Adaptation Working Group for the IPCC's Fourth Assessment Report

- **Debra Roberts**
  A local government practitioner working in Durban, South Africa, where she is responsible for developing municipal-level climate change adaptation plans

- **Shiv Someshwar**
  Director, Institutions and Policy Systems Research, and Director, Asia and Pacific Regional Program, at the International Research Institute for Climate and Society (IRI) of the Earth Institute, Columbia University

In addition, more than 250 global and local experts were consulted in the course of the country test cases. Many of these experts are listed in the Acknowledgements section.

A FRAMEWORK TO ASSESS AND MANAGE TOTAL CLIMATE RISK

The Working Group built the framework on two core beliefs, derived from a review of current knowledge and our own collective experience in the fields of climate change, investments, economics, development, and risk management.

First, it is critical that decision-makers address total climate risk – both current risk and the additional future risk that climate change might present – while acting under considerable uncertainty about the source, probability, and extent of that risk. This principle reflects the finding by the IPCC that "many actions that facilitate adaptation to climate change are undertaken to deal with current extreme events". While the incremental impact of climate change may be important to quantify on a global scale, on a local scale decision-makers must assess the total losses they are likely to face in the future in order to avert them with the most appropriate adaptation measures. When facing, for example, increasingly fierce hurricanes, it is less important for a local decision-maker to identify the proportion of the likely damage that comes from additional climate change than it is to assess the magnitude of the total risk and prepare accordingly.

Applying this principle, we:

- Adopted a comprehensive risk management approach – assessing a location's risk across all climate hazards and economic sectors, and creating a ranking of risks – including quantifying and assigning "price tags" to specific risks

- Used scenario planning to help decision-makers select and prioritize climate adaptation and resilience measures in a situation of uncertainty about future climate. Three scenarios to 2030 were constructed for each location studied: a "base" scenario assuming a continuation of today's climate patterns; and "moderate" and "high" climate change scenarios

Second, climate risk has major potential impact on economic development; many of the measures that can be adopted to strengthen countries' and regions' resilience to those risks are themselves economic development measures[18]. Again, this principle reflects a finding by the IPCC, that "adaptation measures are seldom undertaken in response to climate change alone". Decision-makers should therefore integrate climate adaptation with economic development – rather than tackling climate risk as a stand-alone issue. Thus, the key question is not "How can we minimize the damage from climate hazards?" but rather "How can we reach our development targets while accounting for current and future risks?" Applying this principle to our initiative, we:

- Developed a comprehensive inventory of localized adaptation measures, many of which spanned both climate adaptation and economic development, with the participation of local and international experts and stakeholders from both the climate and development fields. We then derived a shortlist of measures based on a assessment of existing literature and local interviews

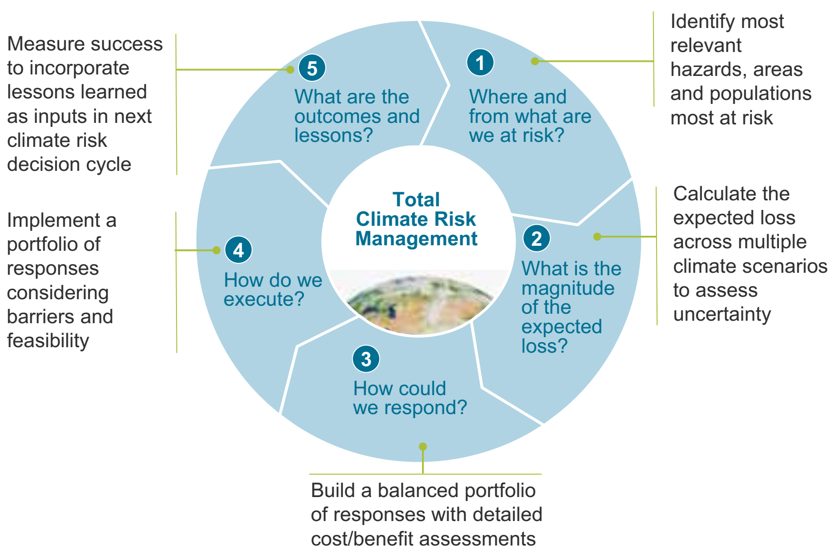
- Applied cost-benefit discipline to derive an effective portfolio of measures for each location, identifying the broader economic benefit of each measure along with its cost[19]

As discussed above, we did not consider broader developmental policies in the test cases, although modification of national policies might significantly enlarge the solution space for climate-resilient development. For example, the option of changing the crops cultivated in a particular region may not align with the national development plans of a given country, but might be the most efficient climate adaptation measure from an economic point of view

It is important to note, as the IPCC has, that countries' climate resilience depends on their socio-economic position, with many developing and least developed countries facing particularly difficult challenges both in addressing current climate risk and adapting to potential climate change – for such countries, it will be all the more vital that climate responses are coordinated with economic development strategies. One should also note that where development policies embrace a low-carbon growth path, the goals of mitigating carbon emissions and improving climate resilience can be pursued in parallel. →

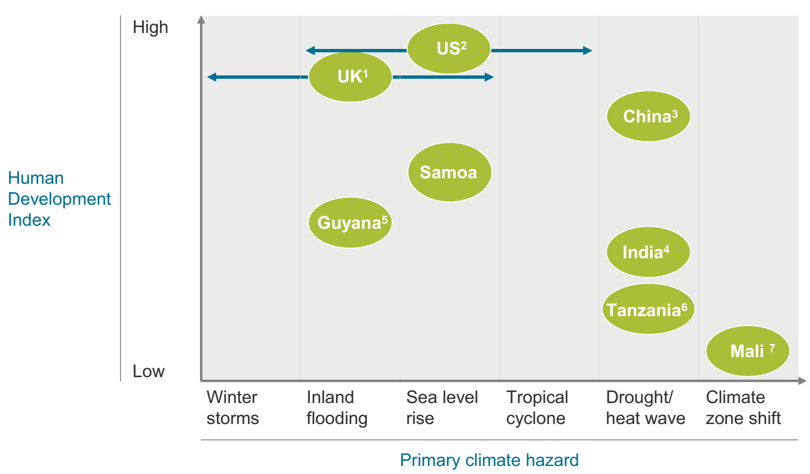
A framework for assessing and addressing total climate risk

04



Overview of country test cases

05



1 Hull
2 South Florida
3 North and Northeast regions
4 Maharashtra
5 Georgetown
6 Central regions
7 Mopti

The key question is not "How can we minimize the damage from climate hazards?" but rather "How can we reach our development targets while accounting for current and future risks?"

The framework derived from these two principles – a tool to assist decision-makers in managing the total climate risk of a country, region or city – poses five questions, each driving a core set of analyses (Exhibit 4):

1. Where and from what are we at risk? Identify the most relevant hazards as well as the areas of the country, region or city that are most at risk given an overlay of spatial distribution of total population, vulnerable populations, and economic value

2. What is the magnitude of the expected loss? Determine what is at stake from the risk by using scenario and probabilistic loss modeling to calculate an estimate of the total climate risk of the location under focus – that is, the risk from current climate, plus economic growth, plus climate change

3. How could we respond? Build a balanced portfolio of responses with detailed cost-benefit assessments, where the cost-benefit ratio is calculated by measuring capital and operating expenditures against total economic benefit

4. How do we execute? Implement a holistic climate risk strategy that overcomes barriers and launches fully funded key adaptation initiatives

5. What are the outcomes and next steps? Measure success, conduct the risk management process periodically adjusting strategies as climate scenarios change

OVERVIEW OF THE TEST CASES

The bulk of the Working Group's efforts were focused on applying this framework consistently across the eight local test cases mentioned below – working on the ground in the countries under study, in close consultation with local experts and decision-makers spanning government, NGOs, business, and communities. To test the applicability of the framework, the case selection deliberately spanned both the developed world – where portions of the analysis required for the effort already existed – and the developing world, where key analytics and data sets needed to be created, for example on physical hazard models, asset and income datasets, and assessments of the vulnerability of infrastructure (Exhibit 5).

The test case locations were:

- North and Northeast China: although China, with its enormous land mass, faces a wide range of climate hazards, this case focused on one key risk in two regions: drought and its impact on agricultural yield in the north and northeast of the country – a particular concern given China's priority of achieving food security. the case was based on Heilongjiang, Jilin and Liaoning provinces for Northeast China, and Hebei, Shanxi, Beijing and Tianjin provinces for North China.

- Georgetown, Guyana: Guyana is a developing country with a tropical climate, located on the north coast of South America. The case was based on Georgetown, the country's largest city, and focused on the risk posed to people, assets and income by rain-related flooding.

- Maharashtra, India: This case was based on Maharashtra, a large state in central India, and focused on drought risk and its impact on agriculture, a major economic sector accounting for 60 percent of the state's employment. The results provided useful insights drought risk for India as a whole.

- Mopti, Mali: Mali is a semi-arid low income country in northwest Africa. This case considered the risk of climate zone shift (a gradual southward shift of the arid Sahara), its impact on agriculture, and possible measures to address this risk. The case focused on Mopti, a key region in central Mali; based on this local analysis, the case also assessed the risk for Mali as a whole.

- Samoa: as a small island developing state in the Pacific Ocean, Samoa is particularly vulnerable to sea level rise. This case focused on the risks of coastal flooding and salinization of groundwater posed by potential sea level rise.

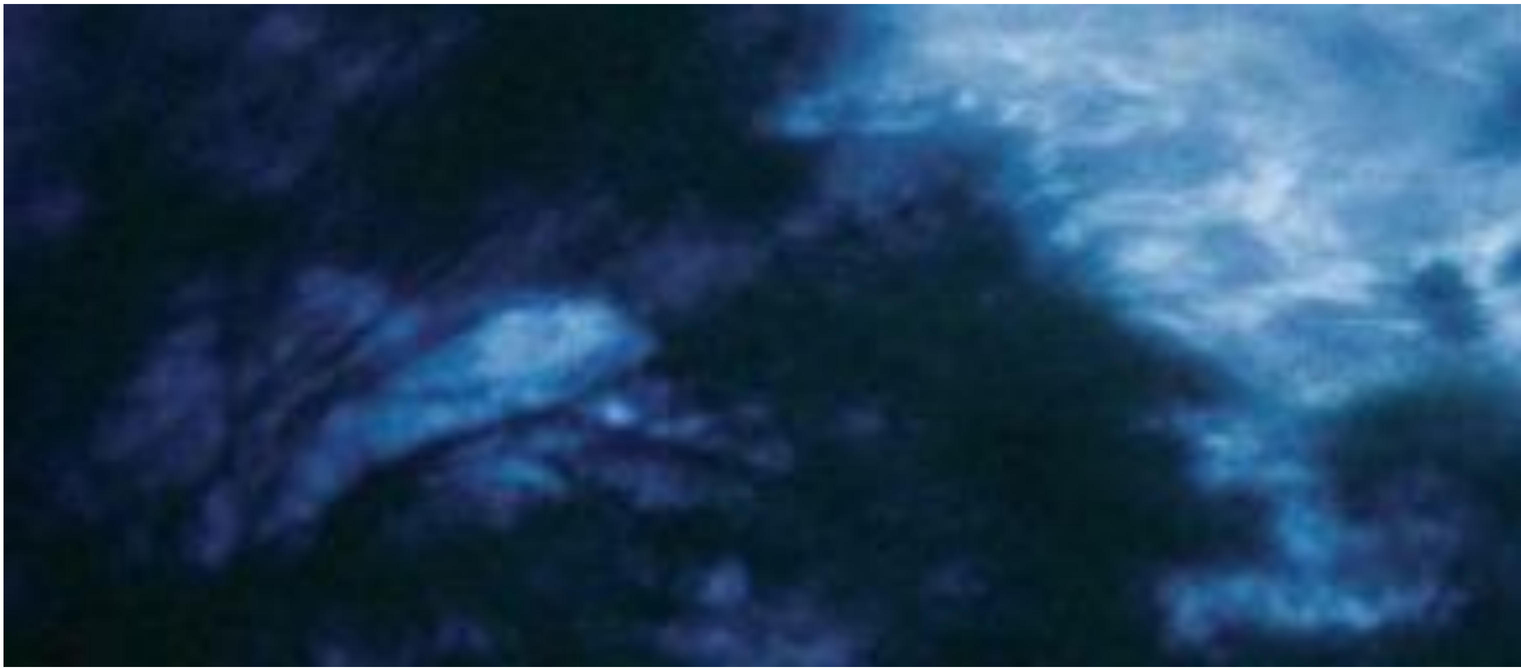
- Central region, Tanzania: a developing country in East Africa, Tanzania is vulnerable to drought on several fronts, including agriculture. This case, however, focused on two specific impacts in the country's drought-prone central region: power production, which relies heavily on hydropower, and public health.

- Hull, UK: the UK case was based on Hull, a medium-sized coastal city at the confluence of two rivers, and focused on the risk posed by coastal and freshwater flood, wind storms, and sea level rise to people, assets, and income.

- South Florida, USA: this case was based on three highly populated counties in south Florida, including Miami, and focused on the risk posed to these urban centers by hurricanes and associated flooding – a risk which could be exacerbated by sea level rise.

The studies were based on broad metrics of climate-related economic loss, such as GDP, asset value, and agricultural production, and in most cases did not attempt to calculate the additional social and environmental costs of climate impacts. In selected studies, however, the methodology was extended to human costs – through an assessment of the health impacts of climate risk – and the losses facing particular economic sectors such as power generation.

While the test cases were focused explicitly on particularly climate-sensitive locations – indeed the ultimate objective of these effort is to help those people most at risk from climate – an adequately wide variety of settings was chosen to test the framework and its replicability. ➔



The final section of this chapter provides an overview of the core steps in the methodology applied in the test cases, while the Methodology Guide, in the Appendix of this report, provides a fuller description and detailed guidance for decision-makers seeking to apply the analysis in their own geographies.

KEY ANALYSES: ASSESSING AND RESPONDING TO TOTAL CLIMATE RISK

The decision-making framework outlined above was applied in each of the test cases, through a systematic methodology.

The first step in this methodology is to identify the most relevant local climate hazards – such as flood, wind, drought or climate zone shift – and the areas most at risk from those hazards in the location under study. The potential loss within these areas is then estimated using three inputs:

- Hazard: Frequency and severity scenarios are developed for most relevant hazard(s), and a map is generated of the impact of those hazards – for example, on public, residential, commercial or agricultural assets
- Value: The risk in the area is quantified in terms of population, assets and income value. To arrive at this output, the area's population and economic value are projected out to 2030
- Vulnerability: The vulnerability of population, assets and incomes to the hazard is determined through the use of "vulnerability curves" that define, for asset classes such as agriculture, residential and industrial/commercial, the percentage of value damaged by hazards of different severity

The estimates generated for these three dimensions were combined to calculate the expected loss for the area under study following a probabilistic loss model approach, for each of the three climate change scenarios – "today's climate", "moderate climate change", and "high climate change". Note that these scenarios were developed independently in each test case based on a combination of global and local projections, recommended by national experts, and so do not correspond to the IPCC scenarios. (See Box: How do we know how much the climate will change?)

Once this potential loss is calculated, the question facing decision-makers remains: "how should we respond?" To answer this question, the methodology identifies a comprehensive set of potential climate resilience and adaptation measures – including infrastructural, technological, behavioral, and risk-transfer measures[20]. In the test cases, we identified a comprehensive set of measures by scanning existing literature including academic and NGO reports, and by interviewing local experts and government officers. The NAPAs developed under the auspices of the

The bulk of the Working Group's efforts were focused on applying this framework consistently across eight local test cases – working on the ground, in close consultation with local experts and decision-makers spanning government, NGOs, business, and communities

UNFCCC were particularly valuable input into the test cases conducted in least-developed countries, capturing as they do deep local knowledge and viewpoints on the most pressing adaptation and development issues. We should note that our objective in the cases was to test and refine the framework, rather than to provide complete answers on adaptation strategy for the locations studied. Given data and time limitations, we did not assess all possible measures. Even in a fully-fledged application of the framework, real-world constraints of time and resources, would force some type of prioritization of the measures to be assessed through the methodology.

The methodology's next step is to filter the comprehensive list of measures and select a shortlist based on the applicability and feasibility of each measure, as determined by local interviews and stakeholder preferences. In an ideal situation, each potential measure in the long list would be quantified. While we focused on concrete measures that can be identified, sized, funded and implemented in the short term, we did not select only those measures that were easy to quantify. In fact, many of the measures evaluated were challenging to quantify, as in the case of mass relocation of agriculture in Guyana or a policy to encourage farmers to plant cash crops in Mali. We nonetheless retained these measures in the quantitative assessment because local stakeholders consider them to be of high-priority.

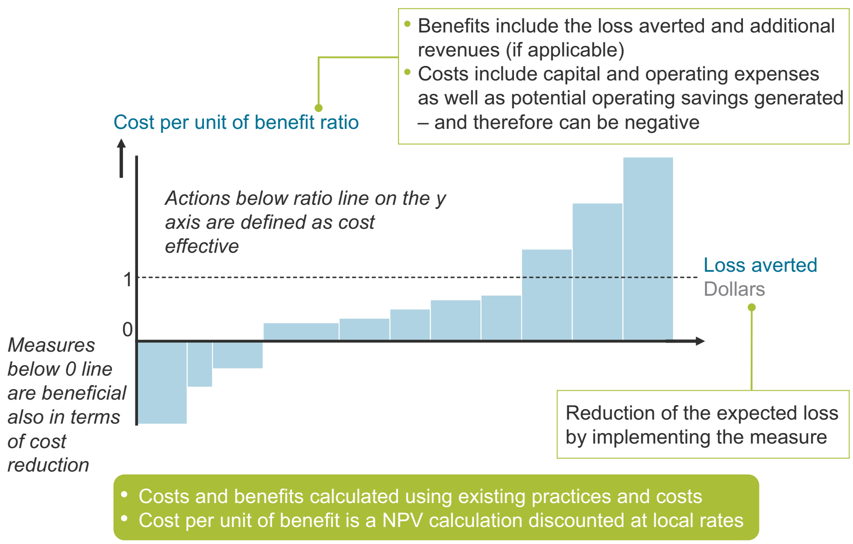
It is important to note that while many of the measures evaluated through this methodology are development measures, adaptation is not about conducting development in a "business as usual" fashion. In part, what makes adaptation different from development is the scale and priority of the measures selected.→

HOW DO WE KNOW HOW MUCH THE CLIMATE WILL CHANGE?

In short, we do not know by exactly how much the global climate will change as a result of increased greenhouse gas emissions. Our work is not predictive. Even widely accepted results, such as those summarized in the IPCC reports, take the format of a range of possible outcomes. In addition, for a specific location, there may be several disagreeing models of climate change, or only one isolated model. To accommodate these uncertainties, we have used scenario planning in our methodology. By choosing a range of climate change scenarios for each test case location, we could represent this uncertainty. Identifying the adaptation measures which are economically attractive under all three scenarios will help decision-makers take action under uncertainty in a rational way.

Adaptation cost benefit concept

06



Cost-benefit approach focuses on loss averted

07

Scale, in that the future climate risk is different from today's, and so the penetration rate of certain measures will be higher than it would be without the increased risk. Priority, in that the measures that address climate risk cost-effectively will be more important than alternative development choices that do not. It is the quantitative understanding of risk that allows such trade-offs.

Next, detailed evaluations are undertaken to determine the societal costs and benefits of each measure, and thus to arrive at a prioritized ranking of the most cost-effective adaptation measures available to the area under study. The end product is a "cost curve" depicting a set of cost-effective measures around which a country can build its adaptation strategy (Exhibit 6). Note that, although we did not consider policy measures such as pricing or planning given the scope and focus of this work, these factors should be included in future, more comprehensive efforts prior to implementation.

Each adaptation measure is plotted on the cost curve, ranging from the most cost-effective on the left of the curve, to the relatively least cost-effective on the right. The horizontal axis sets out the the total extent of the loss averted by the measures. The vertical axis indicates the cost per unit of benefit for each measure – accounting for the capital and operational expenditure required to put those measures in place. The costs of a measure include any cost savings generated by that measure – for example, improved soil techniques, a key adaptation measure in drought-prone agricultural areas, generate net cost savings for farmers.

Additionally, the cost-benefit ratio includes new revenues generated for agricultural measures. We account for revenue as benefits in the denominator of the cost-benefit ratio, but analysis may equally include agricultural revenue as negative costs in the numerator – a conservative approach. The stream of costs is discounted back to today's dollars using local discount rates, as noted in each test case appendix.

For any location, the cost curve will set out three categories of measures:

- Measures that are cost-negative, and that therefore create savings
- Measures with a cost-benefit ratio below 1 – that is, measures whose economic benefits outweigh their costs
- Measures with a cost-benefit ratio above 1 – that is, cost-inefficient measures

Finally, the measures on the cost curve are prioritized and assembled into a portfolio of adaptation measures for the area in focus that addresses the "total climate risk". As with all cost-benefit analysis, the analytical results of the cost curve are intended to start a discussion – they will not provide an explicit answer on what the most effective portfolio of adaptation measures would be for a particular location. The measures that are prioritized in such a portfolio will not necessarily be only the most cost-effective ones – those on the left of the cost curve. Rather, a broader set of selection criteria – covering both evaluation and implementation – will be needed, including measures' potential for impact, their ease of implementation, their synergies, as well their coverage of both low- and high-frequency hazards. We should note that, although cost-benefit analysis creates a valuable fact base for decision-making, it is limited in three ways:

- First, it can accommodate only discrete adaptation options, rather than the full spectrum (for example, it does not work well to assess dikes of a wide variety of different heights, or all possible crop rotations)
- Second, it must be explicitly modified to take into account synergies or dis-synergies between different measures (for example, building a very high seawall against flooding and relocating all houses further back from the flooding zone are mutually redundant measures)
- Third, it necessarily represents a static view – it is based on assumptions about the price of the identified measures, economic growth, and other metrics.

Nonetheless, cost-benefit calculations are commonly used for local and national decision-making, and provide a useful starting point for a quantitative input into the decision-making process on adaptation[21]. Applying this approach in the test cases underlined a number of established lessons on the applicability of cost-benefit analysis. In general, cost-benefit analysis is most appropriate when assessing specific measures that are known and identifiable. It is a particularly good approach in the broader discipline of risk because it helps connect the measurement of risk – the size of the problem – to the evaluation of approaches to decrease that risk. It is most appropriate when there are stable and predictable parameters, when the scope of work is finite and limited, and when the relative costs of executing the work are within an acceptable range. Therefore, cost-benefit analysis must be complemented by consideration of non-economic factors such as barriers to implementation, and social and environmental effects (Exhibit 7). ❍

CHAPTER 2:
TOWARDS SOLUTIONS: FINDINGS FROM THE TEST CASES

Scenarios can be built to guide decision-making under uncertainty | Significant economic value is at risk | In principle, much of the projected loss can be averted | Climate resilience boosts economic development

The analysis conducted in the test cases produced some striking initial findings on the extent of economic value at risk from climate, and on the options for strengthening economies' climate-resilience in cost-effective ways. Although these findings do not constitute full answers to the adaptation challenges of the locations studied, they provide a useful indication of both the extent of the potential loss these locations face, and the costs of averting that loss. The test cases also demonstrate the value of a quantitative economic framework as an aid to decision-making, and show that robust and actionable insights can be generated in a short time even in countries where climate information is limited.

Four findings stand out from the test cases:

- Scenarios can be built to guide decision-making under uncertainty. Despite considerable uncertainty about future climate, we know enough to build meaningful scenarios on which decision-making can be based. Uncertainty about the local impacts of global climate change trends, particularly in developing countries, has hampered adaptation action to date. But even in locations with limited existing research, the test cases were able to build robust scenarios to 2030 and identify a set of adaptation actions that serve as good precautionary steps to prepare for a range of possible climate change outcomes.

- Significant economic value is at risk – both from "today's climate" and from climate change. The test case locations already stand to lose between 1 and 12 percent of GDP annually as a result of existing climate patterns, with poorer populations in some of the developing countries studied at risk of losing an even greater proportion of their income. Yet even within the next 20 years, climate change could more than double these losses as a percentage of GDP, while economic growth is likely to increase the absolute extent of these losses significantly.

- In principle, much of the projected loss can be averted. In the test case locations, between 40 and 100 percent of the annual expected loss in 2030 – even under a scenario of high climate change – can be averted through adaptation measures that are already known and utilized in those locations. In most cases, these measures can be assembled in a cost-effective portfolio – that is, where the costs of adaptation are less than its economic benefits. And in many cases, several of the measures in the portfolio have negative cost – that is, they both avert climate-related loss and generate operational cost savings[22].

- Climate resilience boosts economic development. These adaptation measures are in many cases also effective steps to strengthen economic development. This is particularly so in the agricultural cases, where measures to adapt to climate risk, such as increased focus on cash crops, can generate revenues greatly exceeding the climate-related loss averted by those measures – and so contribute to improvements in national or regional wealth. For example in Mali, greater cultivation of cash crops would provide on the order of $2bn in additional annual revenue for the country.

SCENARIOS CAN BE BUILT TO GUIDE DECISION-MAKING UNDER UNCERTAINTY

Because the greatest risk posed to most economies over the next two decades stems from historical climate patterns, uncertainty over the impact of climate change should not stand in the way of taking immediate action to improve climate resilience. Nonetheless, as the test cases show, climate change could exacerbate the risk significantly even over this relatively short time horizon, and have a disproportionate impact on poor and vulnerable populations. It is therefore important that decision-makers factor the possible impacts of climate change into their planning – despite the uncertainty over the extent and nature of that impact in any given location.

UNCERTAINTY IN LOCAL CLIMATE CHANGE PROJECTIONS

Predicting future climate is an inexact science, all the more so when scientists attempt to translate observed global trends into specific local forecasts. As discussed in Chapter 1, there is growing agreement among many scientists that global warming is already sparking climate change in most regions of the world, and that in turn could already be leading to shifts in rainfall and

storm patterns, and sea level rise. However, our test cases have shown just how difficult it is for scientists and decision-makers to settle on clear forecasts of the impacts of these changes at the local level – a problem reinforced by the fact that local data is often incomplete, particularly in developing countries.

In Guyana, for example, the limited available data pointed to two possible – and contradictory – impacts of global warming on rainfall patterns: a decrease in rainfall by some 5 percent to 2030, which would lessen flooding, and an increase of 10 percent, which would worsen it significantly. In Mali, existing studies pointed to a similarly wide range of possible outcomes on rainfall, which might rise or fall by up to 10 percent in either direction – with quite different impacts on agriculture. In Florida, a location with a much greater base of scientific data, there was nonetheless substantial divergence between existing studies on the likely local impact of global warming. For example, one authoritative study found that 1 degree Celsius of global warming would increase hurricane wind speeds by 8 percent, while another put the figure at just 2 percent.

USING SCENARIO PLANNING

Scenario planning has been used as a tool for decision-making under uncertainty in many different applications. The general concept is to construct scenarios to a particular future date, around the variable that has the greatest and most relevant uncertainty for the users – for example, oil price, GDP growth, or political direction. To help local decision-makers address the potential risk posed by climate change, we developed scenarios to 2030 for each of the test case countries, modeling the economic loss expected from different levels of climate change and their impact on the hazards applicable to the cases. Drawing on all available local and global data, and numerous interviews with experts, we constructed three (and in some cases more) plausible climate change scenarios to 2030 for each test case. For most of the studies, the scenarios were:

- "Today's climate" – a scenario assuming no impact of climate change, modeling a continuation of historical weather patterns alongside expected economic growth to 2030. Note that other factors unrelated to climate change can also increase today's risk. For example, in Samoa, geological subsidence may exacerbate the effects of climate change-driven sea level rise

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In Guyana, for example, the limited available data pointed to two possible – and contradictory – impacts of global warming on rainfall patterns: a decrease in rainfall by some 5 percent to 2030, which would lessen flooding, and an increase of 10 percent, which would worsen it significantly.

- "Moderate change" – a scenario built on the average forecast of climate change for the particular hazard(s) in the location under study, drawn from all available studies and expert interviews. For example, the "moderate change" scenario for Guyana was for a 4 percent drop in monthly average rainfall to 2030, while in Florida this scenario was based on a 3 percent increase in wind speed

- "High change" – a scenario built on the outer range of the climate change considered possible to 2030 by existing studies and experts consulted. For Guyana, this scenario was for a 9 percent increase in monthly average rainfall; in Florida, it was for a 5 percent increase in wind speed. The "high change" scenario is valuable in that it gives decision-makers a science-based indication of the probable maximum extent of the risk posed by the hazard(s) in question over the period of the scenario. An informed judgment can then be made on the extent to which this risk should be protected against, based on the costs and benefits of the available measures and the location's broader development priorities. Awareness of the potential impact of "high change" can also inform development choices, such as the site of new assets. In the test cases, the "high change" scenario was developed using the upper end of conditions described in the majority of IPCC reports and global circulation models published and accepted as likely by the scientific community. More recent scientific evidence was applied in rare circumstances for which the scientific publications suggest even the highest IPCC predictions may be much too conservative (for example, sea level rise). Therefore, the reader should not consider the "high change" scenario as an extreme or unlikely forecast. →

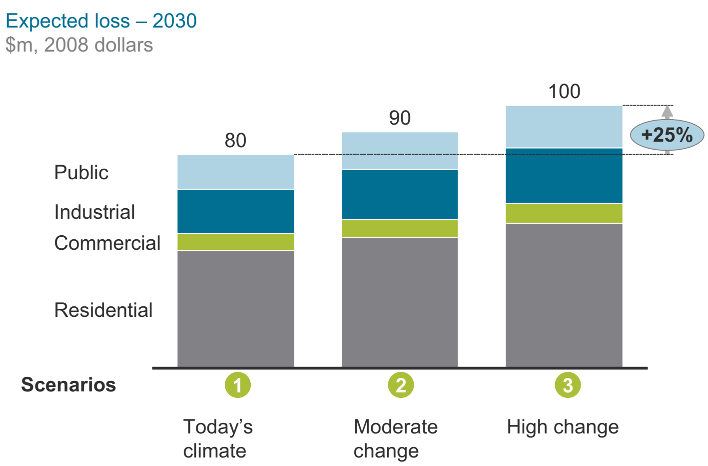
It should also be noted that effective adaptation decision-making will depend greatly on the robustness of the climate change scenarios available. Therefore, such scenarios will require periodic review and updating as new data from climate observations and models become available.

To calculate the economic loss resulting from each scenario, the hazard impact of the scenarios is assessed against the location's total asset value (agricultural production in the case of Mali, for example, and residential, commercial and public infrastructure in case of Hull) as well as the vulnerability of those assets to the hazard in question (based, for example, on historical event data and insurance experience). The loss calculation also depends on a number of assumptions being made, based on existing scientific and economic knowledge: for example, the Guyana study made the assumption, based on historical data, which an increase in monthly rainfall would translate into a linear increase in flood heights. Similarly, we assumed sea level rise in Samoa causes a shift in the recurrence curve for coastal flooding events. This means that, if, for example, sea level rises by 20cm in the future, then a 2.0m inundation will occur with the same frequency as a 1.8m event occurs today.

This process enables the decision-maker to arrive at a robust comparison of the probable loss that would occur under each of the three climate change scenarios, broken down by asset class (see Exhibit 8 for the example of Hull,UK) or hazard (Exhibit 9 for the example for the three counties studied in Florida,US).

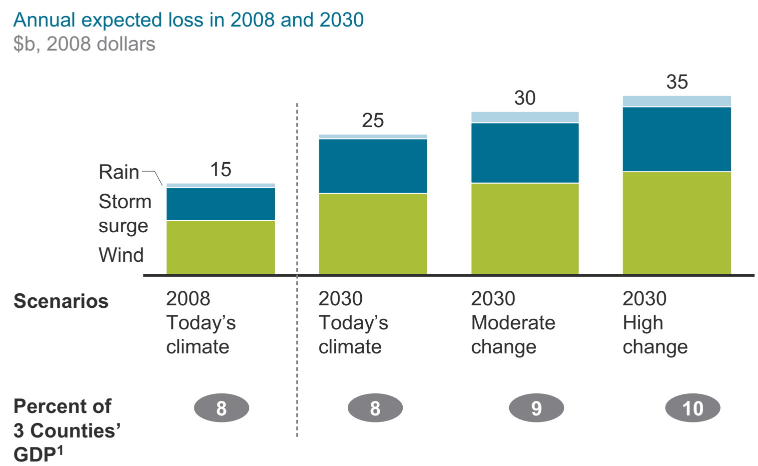
08

Loss across different asset classes for the climate change scenarios – U.K. test case



09

Loss in different climate change scenarios by hazard – Florida test case



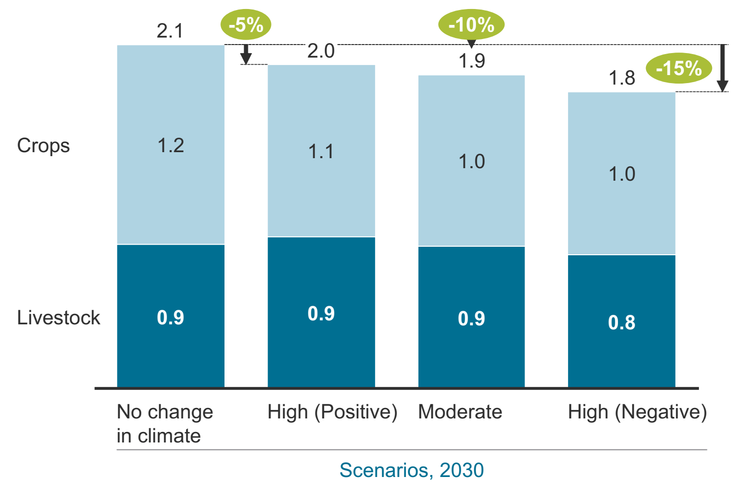
1 2008 Moody's

Scenarios are a flexible tool and can be tailored to the potential impact of climate change on a particular location. In Mali, for example, where we approached climate change from the perspective of changes to average temperature and precipitation, the scientific view was that an increase and a decrease in rainfall were equally plausible under global warming. We therefore constructed two scenarios of high climate change, both of which assumed in increase in temperatures, with one (the positive case) based on an 8.1 percent increase in rainfall and the other (the negative case) on a 10.6 percent decrease. These scenarios were used to model the potential range of climate change impacts on crop and livestock production to 2030 (Exhibit 10).

10

Annual value of crop and livestock production – Mali test case

$bn, 2008 dollars



SIGNIFICANT ECONOMIC VALUE IS AT RISK

As discussed in Chapter 1, any given location will face three categories of future climate-related loss: that caused to existing assets and income levels by a continuation of today's weather patterns; that brought about by economic growth which exposes greater asset value to climate risk; and finally, any additional loss that may be caused by climate change. The test cases revealed that the locations studied already stand to lose between 1 and 12 percent of GDP annually as a result of existing climate patterns. When the effects of economic growth and climate change are added to these figures, the total potential climate-related loss to 2030 rises to as much as 19 percent of GDP, in the case of Georgetown in Guyana, and 6 percent of agricultural production →

ESTIMATING THE EXPECTED LOSS FROM CLIMATE RISK

We adopted a "natural catastrophe method" used commonly in the insurance industry to estimate the expected climate-related loss in a specific location. This method relies on the selection of a natural hazard event and then a detailed analysis of hazard frequency and severity as well as of the spatial distribution of assets. Further discussion on the rationale for this approach – and on alternative methods for estimating loss – is provided in the Methodology Appendix.

in the case of China (Exhibit 11). Even in the next 20 years, climate change could create significant incremental risk: climate change drives 45 to 70 percent of the expected additional loss over this period, with economic growth driving the remainder of the loss (Exhibit 12). (See Box: Estimating the expected loss from climate risk.)

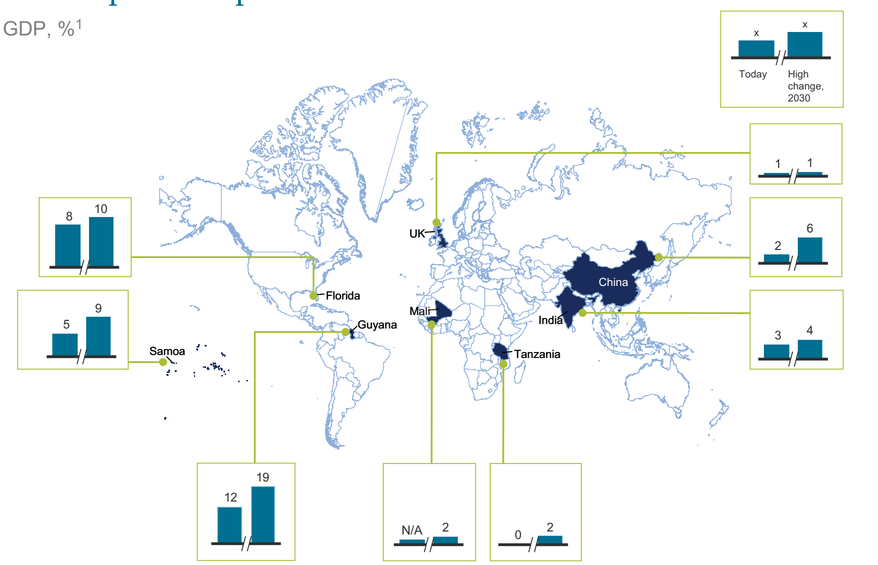
The prominence of current risks is a recurring theme in most of our test cases. In fact, our analysis shows that climate risk is already present and significant, and that only a limited number of societies have already taken adequate steps to address it. In addition to the future effects considered in our scenarios, environmental stresses and degradation of natural resources occuring now may have impacts that are difficult to predict. These can include compound effects, where two or more disturbance factors feed back with each other leading to unforeseen phenomena. Further, due to the complexity of natural systems, changes in the temperature or precipitation of a location may have indirect, or "non-linear" outcomes, such as emerging pests or diseases. These factors are likely to exacerbate the impacts of climate change and so our estimates of total climate risk may well be conservative.

We should emphasize that our estimates of climate-related loss are not comparable to those of other publications, because of the significant methodological differences between our study and others. Our assessments of total climate risk are naturally greater than estimates of the costs of adapting to climate change alone because our methodology includes loss from today's climate, future climate and anticipated economic growth[23].

11

GDP impact of expected loss

GDP, %[1]



1 Based upon select regions analyzed within the countries (e.g., Mopti, Mali; Georgetown, Guyana Hull, UK; North and Northeast China; Maharashtra, India; Central regions of Tanzania; Southeast Florida, U.S.)

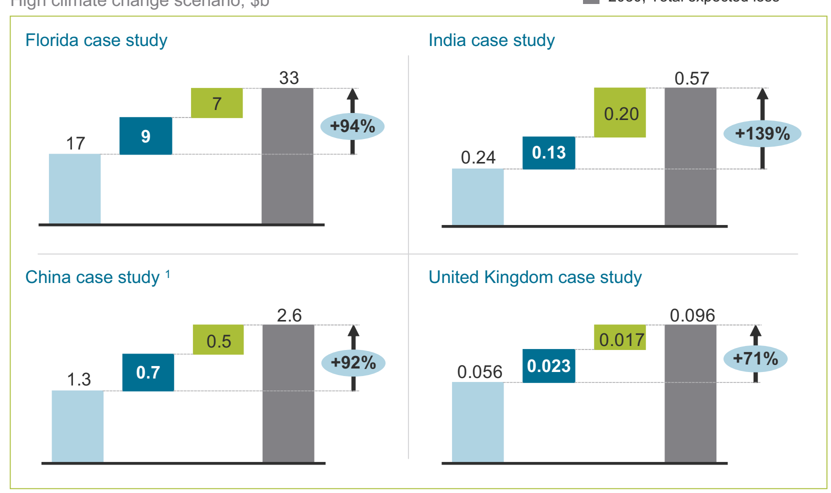
12

Driver of future expected loss – asset growth vs. climate change

Expected loss from exposure to climate

High climate change scenario, $b

2008, Today's expected loss
Increase from economic growth, no climate change
Increase from high climate change
2030, Total expected loss



1 Based upon moderate climate change scenario data and analysis

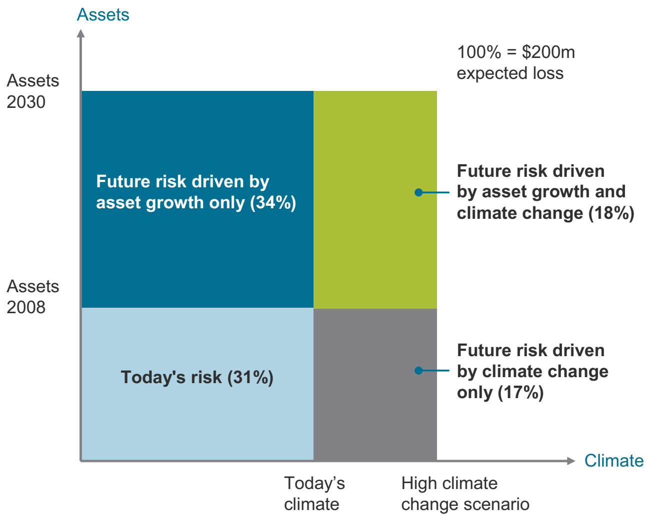
Additionally, while we present our analytical findings as single numbers in this report for the sake of simplicity, these numbers must of necessity be considered as indicative, as they are built off several assumptions made in developing the climate change scenarios and calculating losses.

EVALUATING TOTAL CLIMATE RISK

The finding discussed above underlines the need for decision-makers to evaluate and address the total climate risk faced by their economies – both historical risk

13

Relative importance of expected loss drivers – Guyana test case



and the additional future risk posed by climate change. The risk posed today is often significant and this pre-existing adaptation deficit – that exists either by choice or implicit practice – needs to be addressed. Note that, in our test cases – with the exception of Hull in the UK and South Florida in the United States – we evaluated the total climate risk from a single category of climate hazard. Nonetheless, the damage from a single category of climate hazard, such as hurricanes, may depend on several physical processes, including storm surges (exacerbated by sea level rise) and winds (exacerbated by changes in global circulation). The methodology described in this report could easily be applied to multiple categories of climate risks, such as flooding and climate zone shifts.

For an illustration of the "total climate risk" approach in action, consider the case of Guyana, and the risk posed by freshwater flooding to the economy of Georgetown, its largest city. Georgetown is already exposed to major flood risk from severe rain, and much of the city is inundated during the rainy seasons, causing considerable economic disruption. Continued development of the city in the face of this flood risk will put greater value at risk – even if there were no increase in rainfall from climate change. As Exhibit 13 shows, the bulk of the $200m in value at risk in Georgetown is driven by the exposure of existing assets to today's climate, and the growth of those assets and their consequential exposure. This analysis shows that decision-makers in Guyana would very likely benefit from focusing immediate efforts on protecting assets from current flood patterns, and steering future development towards less flood-prone areas. These steps would be likely to create a sound foundation for any additional efforts required to adapt to climate change.

In Florida, an area with a much greater level of economic development, a similar outcome held true. The three Miami-area counties assessed already face substantial risk from hurricanes – with an annual expected loss for 2008 quantified at $17bn, or almost 10 percent of the counties' combined GDP. A continuation of current development patterns in the face of historical climate risk would increase both GDP and the annual expected loss, to $26bn in 2030. Were climate change to increase the severity of hurricanes, the Miami area could face an additional $4-7bn in loss. Again, the implication is clear: decision-makers' immediate focus could be on protecting existing assets, and improving the climate-resilience of future development. These measures would in any case help to prepare the area for potential climate change impacts.

It should be noted that Florida's exposure to hurricanes makes its level of climate vulnerability unusually high. The test case in Hull (UK), on the other hand, underlined the fact that developed countries are generally better adapated to climate risk than poorer countries. Although Hull was identified as the UK city most exposed to the risk of flood and storm surge, the study found that the city's annual expected loss from these hazards in 2008 stood at less than 1 percent of its GDP – or some $50m. Economic growth would increase the expected loss to almost $80m in 2030, while increased flooding and sea level rise in a high climate change scenario would bring the total loss to almost $100m in 2030 – a significant figure, but still no more than 1 percent of local GDP. It is worth noting than an assessment of the vulnerability of London to increased flooding found that existing flood-protection measures, notably the Thames Barrier, would protect the city even in a high climate change scenario to 2030[24].

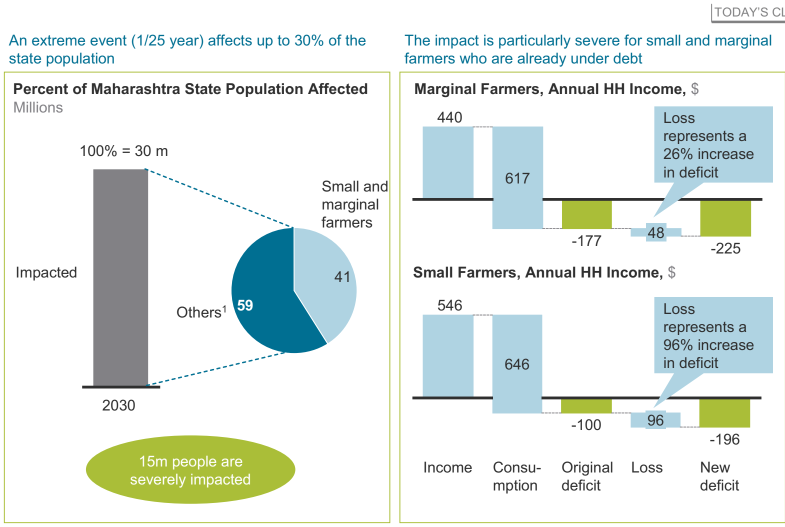
POORER POPULATIONS FACE PROPORTIONATELY GREATER LOSS

Previous studies have found that populations with lower per capita income are particularly vulnerable to climate-related loss[25]. The Maharashtra (India) and Mopti (Mali) cases, which →

Severe impact of an extreme event on small and marginal farmers – India test case

14

TODAY'S CLIMATE



1 Others include other farmers & non farmers

focused on the risk posed to agriculture by climate, provided stark evidence in support of this concern. Maharashtra relies on rainfall for much of its agriculture and is already vulnerable to drought. This is reflected in the current figure for expected annual loss from drought, which stood at $240m in 2008 – equivalent to nearly 3 percent of the state's agricultural output. Agricultural income growth would increase the loss to $370m by 2030, while the high climate change scenario with more frequent droughts would increase the expected annual loss to $570m by 2030 – or 4 percent of the region's agricultural output.

In Maharashtra's case, these global figures mask the much greater vulnerability of food production and the rural poor. In a drought year, some 30 percent of the state's food grain production would be lost – even without climate change. This would have particularly severe impact on the 15 million people engaged in small and marginal farming, who typically have no reserves to see them through lean years (Exhibit 14). For India as a whole, such a drought in 2030 could lead to a countrywide agricultural loss of more than $7bn, severely affecting the income of 10 percent of the population. These losses could be much greater in a scenario of high climate change, as drought events that have historically occured once every 25 years could now occur once every 8 years. Again, drought protection measures implemented now will address Maharashtra's large current climate risk – and strengthen the state's preparedness for a possible increase in drought frequency caused by climate change.

In Mali, we tested the potential impact of gradual climate zone shift – essentially, a slow southward expansion of the arid Sahara – on agriculture, which accounts for more than 80 percent the country's employment. A scenario of high climate change to 2030 would reduce Mali's income from agriculture and livestock by 14 percent compared to a scenario of no climate change (although overall output would still be higher than today, even in the worst-case scenario, thanks to agricultural growth that will likely track with population growth).

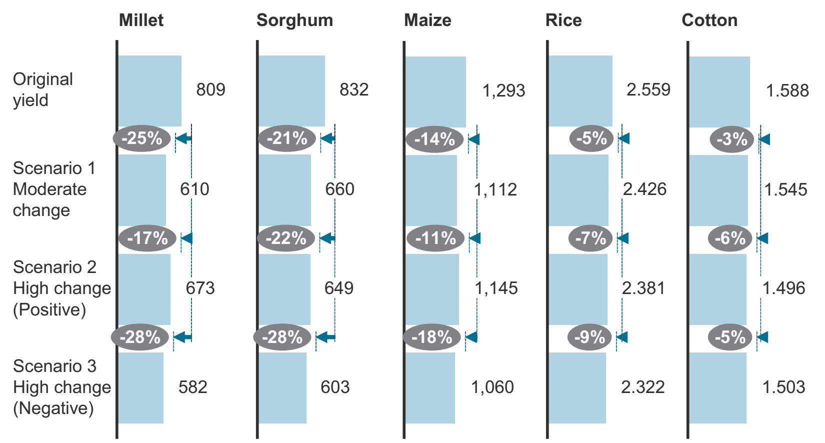
Again, the detail of the test case reveals more severe local impacts: the projected losses are concentrated in the regions and amongst the crops most affected by climate change. For example, yields of millet and sorghum, two staple crops, could decline by as much as 28 percent (Exhibit 15) – with serious consequences for low-income and subsistence farmers. Even in the higher-rainfall "best case" scenario for Mali, agricultural crop modeling by International Food Policy Research Institute (IFPRI) pointed to crop losses because greater rainfall can cause greaterer nutrient leaching and the additional rain would largely fall at times when water was already abundant and not needed by the crops. The detailed modeling by crops highlights how complex the issue of agricultural impact from climate change. As in the other test cases, many of the measures which Malian decision-makers could take to protect against these potential losses would in any case be effective steps to improve agricultural productivity. Consequently, a sound strategy to adapt to climate change would be built on the foundation of pragmatic economic development actions.

The Samoa test case confirmed the hypothesis that Small Island Developing States are particularly exposed to high risk. In 1990, the country was hit by Cyclone Ofa, which destroyed buildings, infrastructure, and crops through wind and flooding damage. Due to sea level rise, the frequency of events with Cyclone Ofa-like intensity will likely increase from once every 50 years to once every 20 years in 2030 in the high climate change scenario. As a result, annual expected loss might increase from 5 to 8 percent of GDP in Samoa. Note that, due to its volcanic

15

Impact on yields in each of the modeled climate scenarios – Mali test case

Kg/ha



nature, Samoa has plenty of high ground to which the population can move – although at significant cost. Conversely, the effects of sea level rise will be much more severe on atolls or other low-lying islands, where the population cannot simply relocate to a higher elevation.

Note that, although we utilized spatially resolved asset distributions to calculate the expected loss under each scenario in each test case, we did not take into account distributional variation in the effectiveness of the measures. For example, a measure designed to protect houses may alleviate more damage in a solid, costly house than in a less solid structure. An additional step could be added to our methodology to, for example, document costs and benefits for population groups differentiated by income quartiles.

Although the main focus of this initiative has been on the economic impact of climate risk, the methodology has also proved effective for projecting the non-economic losses from various future climate scenarios. Human health was identified a key climate-related risk in central Tanzania, and was thus made a focus of the test case in that country. Under the increased drought conditions modeled under moderate and high climate change scenarios for Tanzania, cholera cases in the central region are projected to increase by 20-30 percent to 2030. Cases of trachoma, an infectious eye disease that causes blindness, are projected to increase by 100-400 percent under these scenarios. The proportion of region's population under food stress could double.

As in the other test cases, many of the measures which Malian decision-makers could take to protect against these potential losses would in any case be effective steps to improve agricultural productivity. Consequently, a sound strategy to adapt to climate change would be built on the foundation of pragmatic economic development actions

THE ADVANTAGE OF EARLY ACTION

All in all, the test cases make it clear that climate puts substantial economic value at risk, across geographies, development stages and the types of climate hazard. Yet the bulk of this risk is known today, and much of the increase in projected loss would come from economic growth. For decision-makers in all countries, there is much to be gained from acting early to strengthen their economies' resilience to today's risk, and guide overall economic development in a more climate-resilient direction. Not only will ➔

this address today's greatest climate-related losses, it will also be an important precautionary measure against a range of possible climate change scenarios – including those towards the severe end of the range.

IN PRINCIPLE, MUCH OF THE PROJECTED LOSS CAN BE AVERTED

Having identified the climate hazards from which a location is most at risk, and having quantified the probable loss from those hazards under the various climate change scenarios, the next step for a decision-maker is to identify measures to minimize that loss. A key question for the Working Group on undertaking this effort was: would societies be able to assemble a sufficiently cost-effective portfolio of measures to reduce their climate risk and adapt to possible climate change?

In principle, the answer for most of the locations analyzed is "yes". In these locations – themselves selected as regions that are particularly vulnerable to climate – there is a set of cost-effective measures that could address between 40 and 100 percent of the identified climate risk to 2030, both from "today's climate" and from the climate change scenarios. Of course, these are economy-wide figures: within each location studied, there may be populations or assets, such as communities in informal housing on low-lying land, which are more difficult to protect from climate risk. And we should emphasize that this analysis does not speak to the implementation of the loss-aversion measures identified, which may itself be a challenging and complex process. On a positive note, though, continued work towards climate adaptation is likely to reveal additional, innovative adaptation measures that may further increase the fraction of damage averted.

A SHORTLIST OF KNOWN, TESTED MEASURES

In each of the test cases, a thorough process of local and global research and stakeholder engagement was undertaken to identify and evaluate a full range of measures that would be effective in reducing the climate-related loss expected. Only measures that were already known, tested – either in the test case country or internationally – and readily applicable were included in this analysis. We filtered the measures by answering a sequence of questions. Is the measure feasible given the funding, political environment, technical capabilities and time required? Is the measure applicable to the local setting, recommended by local experts, and known to work in the setting? Are the measure and its results desirable? Does the measure decrease risk while fitting with wider policy goals? The resulting short-list of measures was then evaluated quantitatively.

Most of the measures identified were focused on risk prevention and mitigation, in three main categories:

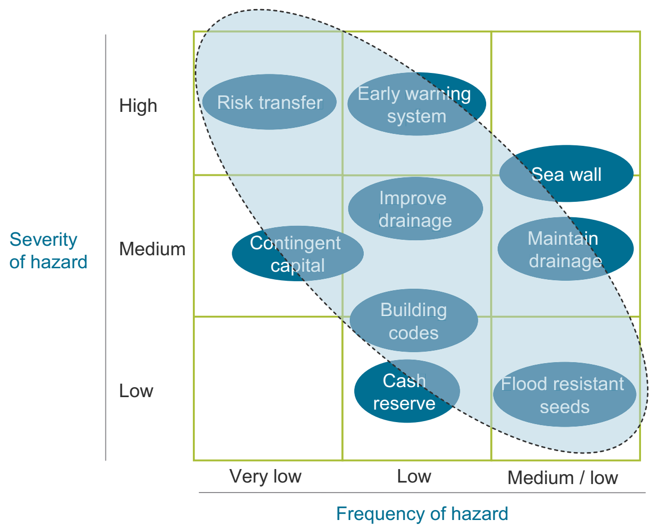
- Infrastructure/asset based responses: measures that require physical changes to existing assets or building of new assets. In hurricane-prone Florida, for example, such measures included "beach nourishment" – extending beaches into the sea to lessen storm surge impact – and strengthening and securing the roofs of residential buildings. In flood-prone Samoa, for example, infrastructure/asset based measures included planting mangrove tree buffers to disperse wave energy, and elevating coastal homes on stilts.
- Technological/process optimization responses: measures that require adoption or use of a different technology, process, or input. In Maharashtra (India), for example, measures considered to protect agriculture from drought included improved fertilizer application, and wider use of mechanical and electronic timers to improve the effectiveness of irrigation.
- Systemic/behavioral responses: measures that involve behavioral change or a coordinated systematic response. In Hull (UK), for example, measures considered to protect the city from flood risk included an awareness campaign for local residents – encompassing an online tool to assess their homes' individual risk profiles – and improved emergency response training.

In most of the cases studied, however, there was a possibility of low frequency/high severity weather events for which the cost of prevention measures would be prohibitive. Consequently, a range of risk transfer measures, including insurance and alternative financial solutions, was considered for inclusion in the portfolio of adaptation measures for each case. Even amongst poorer households in developing countries, such measures could prove a useful complement to prevention measures. (See Box:

16

A climate risk portfolio – balancing cost-effective measures across a range of hazard events

ILLUSTRATIVE



The role of risk transfer on the next page). Exhibit 16 highlights how consideration of a range of severity and frequency of events will help a decision-maker build an effective portfolio of adaptation measures. The measures listed in the exhibit are illustrative.

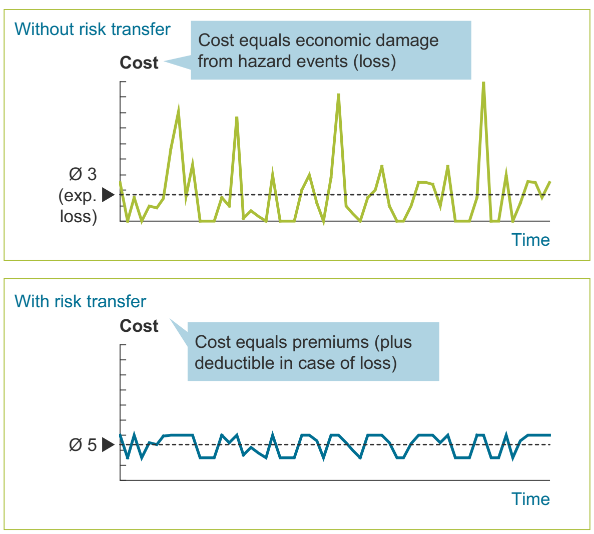
In identifying steps to address climate risk, the test cases also took account of measures that were already being implemented to promote economic development, but which would also serve to strengthen climate resilience – for example, canal lining and rehabilitation of irrigation systems in the case of Indian agriculture. Note that climate adaptation measures do not necessarily overlap with broader economic development measures, and so may entail opportunity costs as well as direct costs. For example, the expense of building a sea wall against an anticipated increase in flooding severity not only represents a cost related to climate risk, but also may limit the funding and leadership and organizational capacity available for broader development measures such as agriculture or sanitation improvements. ➔

THE ROLE OF RISK TRANSFER

17

The main functions of risk transfer

ILLUSTRATIVE



Risk transfer

Benefits

- Caps losses, protects livelihood from catastrophic events
- Smoothes costs, reduces volatility
- Increases willingness to invest
- Provides incentives ("price signals")

Costs

- Expected loss plus markup for production and distribution

Risk transfer methods include traditional, indemnity-based insurance, parametric index solutions and catastrophe (CAT) bonds, and similar financial mechanisms. Exhibit 17 illustrates the benefits and costs of risk transfer solutions from a decision-maker's perspective: risk transfer caps losses and smoothes the costs of climate events to individuals, corporations and governments. It can thus protect livelihoods from catastrophic events and increases the willingness of decision-makers to invest in economic development. These benefits come at a price, however. To be economically viable, insurers or other producers of risk transfer solutions need to charge the expected loss plus a mark-up for production and distribution. Therefore, risk transfer solutions generally exhibit a cost-benefit ratio larger than one in our cost-benefit methodology which is based on expected costs and benefits.

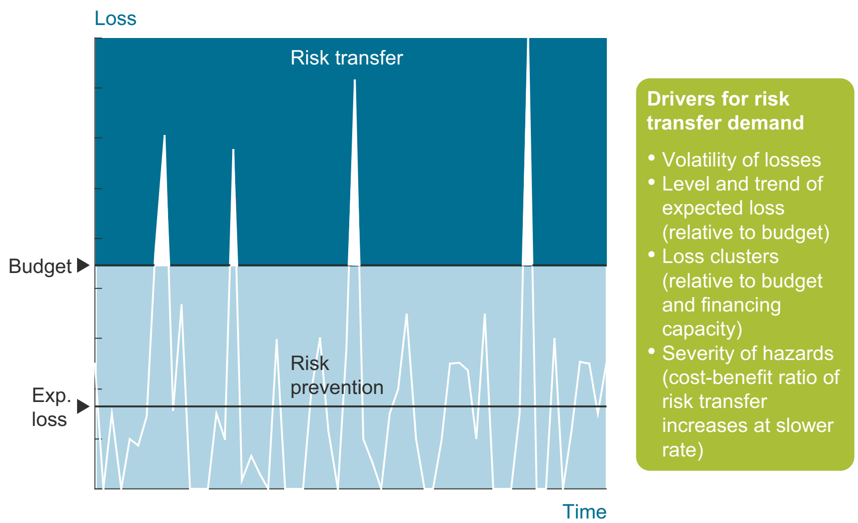
Together with risk prevention and mitigation measures, risk transfer plays an important role in strengthening climate resilience. Prevention efforts can reduce exposure and damage resulting in lower expected loss and thus risk transfer costs. On the other hand, risk transfer can significantly reduce the cost of prevention and mitigation by bearing the risk of rarer or extreme events. For instance, it is rarely economically viable to construct a building to withstand the most extreme windstorms. The more efficient solution is to design for severe windstorms, and then transfer the risk of more extreme events. In the Samoa case, for example, risk transfer proved to be the economically optimal solution to tackle residual storm risk, with physical measures being significantly more costly.

As decision-makers look across the broad breadth of adaptation measures, it is vital for them to find the right balance between risk prevention and mitigation, and risk transfer measures. Exhibit 18 lists the most important demand drivers for risk transfer solutions.

Complementary role of risk prevention and transfer

18

ILLUSTRATIVE



In a similar vein, the Organisation for Economic Co-operation and Development (OECD) notes:

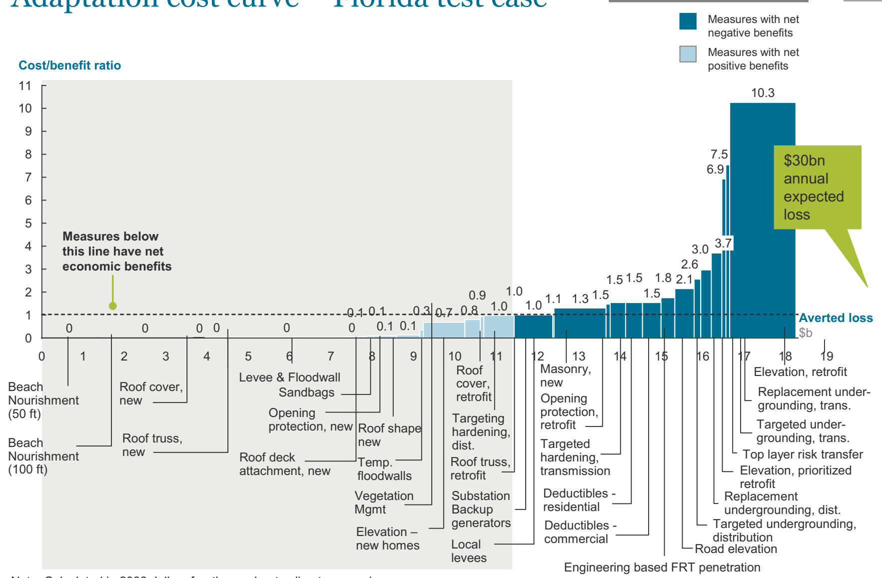
> "Insurance has a dual role with respect to adaptation. Access to insurance payouts can lessen the net adverse impact of climatic events on policy holders. At the same time, insurance is also an instrument for incentivizing adaptations aimed at reducing climate risks. Properly set insurance premiums can, in principle, send appropriate signals to policy holders to undertake adaptation measures to reduce exposure to various risks, including those posed by climate change."[26]

Risk transfer already makes a major contribution to the developed world's relative climate resilience. There are, however, opportunities for risk transfer to play a much greater role in protecting against climate risk in the developing world. For example, weather-based index insurance is an attractive option for a developing world agricultural sector such as in India. These insurance products are limited to an index such as rainfall, temperature, humidity, crop yields, or satellite-based vegetation rather than to actual losses. Administrative costs for these products are low, as no case-by-case damage assessment is required. Moreover, index insurance products do not present the risk of adverse selection, thuse ensuring a higher level of fairness by limiting cross-subsidies between policy-holders. This type of insurance therefore offers simple, cost-effective coverage to small farmers, who – in the case of catastrophic events – are paid out quickly.

19

Adaptation cost curve – Florida test case

MODERATE CLIMATE SCENARIO

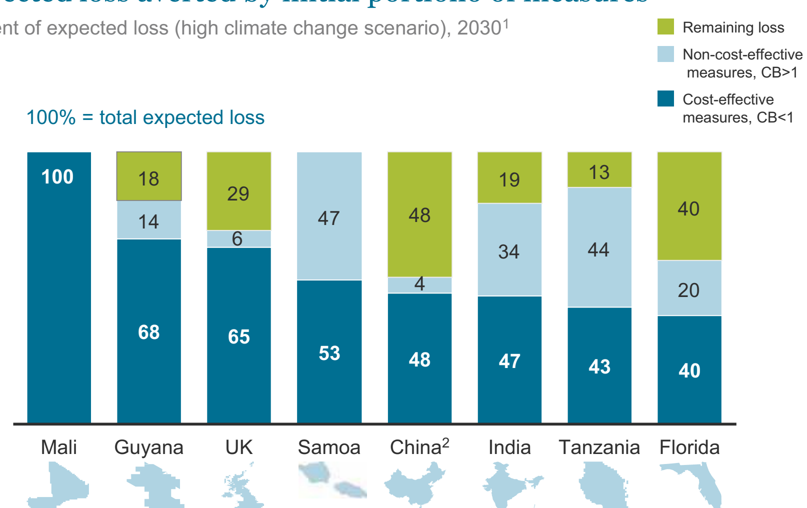


Note: Calculated in 2008 dollars for the moderate climate scenario

20

Expected loss averted by initial portfolio of measures

Percent of expected loss (high climate change scenario), 2030[1]



1 Based upon select regions analyzed within the countries (e.g., Mopti, Mali; Georgetown, Guyana Hull, UK; North and Northeast China; Maharashtra, India; Central regions of Tanzania; Southeast Florida, U.S.)
2 Based upon moderate scenario data and analysis

COST-BENEFIT ANALYSIS

We then applied a thorough cost-benefit analysis to each of the measures identified. In an agriculture-focused case such as China, India or Mali, the capital and operational costs of each measure – better irrigation control, say, or improved fertilizer use – are calculated and weighed against the measure's benefit in terms of improved revenue, as well as the drought-related loss it would avert. (See box: Calculating costs and benefits of adaptation measures. For a full explanation of the cost-benefit approach, see the Methodology Guide in the Appendix of this report).

This cost-benefit assessment of measures can be expressed as a "cost curve", as in the Florida example (Exhibit 19). Measures are plotted along the cost curve, from the most cost-effective on the left, to the least cost-effective on the right. Measures with a cost-benefit ratio less than 1 have a net economic benefit: in this Florida example, for the moderate climate change scenario, measures such as beach nourishment and roof strengthening would have economic benefits that significantly outweigh their costs. We should emphasize that the cost curve is a quantitative tool to assist decision-makers in selecting adaptation measures – it is not a prescriptive answer on what suite of measures ought to be implemented to address climate risk. (See Box: Reading the cost curve.) As we explain below, it remains the decision-maker's responsibility to assemble a prioritized portfolio of climate resilience measures for their location, based not only on the costs and economic benefits of the measures available but also on a range of

READING THE COST CURVE

The cost curve is a useful tool to help decision-makers understand the options to address increased impact. It is not prescriptive – it does not tell decision-makers what suite of measures they ought to implement to address climate risk. However, it quantifies the economics of a subset of measures to address climate-driven hazards for a given scenario and time period. It therefore helps answer practical questions like: What kind of measures are available? How much do they cost? What is the optimum penetration? How much will they reduce the climate risk?

The cost curve evaluates the performance of the measures based on how well they reduce expected loss, on the assumption that reducing future losses from climate change is one of decision makers' key objectives. The detailed estimates underlying each rectangle in the cost curve also allow decision-makers to gauge the financial resources needed to address the risks posed under each climate scenario, as well as a rough an indication of where resources may be allocated most effectively from a purely economic perspective. As in all scenario planning exercises, the resulting estimates cannot be considered a precise prediction but rather an general map that can guide decision making.

other considerations such the ease of implementing measures, and non-economic policy goals.

The cost curves developed in the test cases show that, across the locations studied, between 40 and nearly 100 percent of the expected loss to 2030 can be averted through cost-beneficial adaptation measures that are already known and tested. In most cases, these measures can be assembled in a cost-effective portfolio, where the costs are less than the economic benefits and address approximately half of the expected annual loss (Exhibit 20). This is not to say that adaptation is free: the measures identified would require major upfront investment, and there may be non-economic costs, such as social and environmental losses, which the cost curve does not account for. Yet many of these measures are in fact investments in a national economy and may also have benefits above and beyond the averted loss and additional revenue of agricultural production that we assess.

In each test case, the location's cost curve was constructed for each climate change scenario. This step allows decision-makers to compare the relative priority of the costs and benefits of particular measures under these different scenarios, and thus focus on measures that are economically attractive under all scenarios – an effective way to address the uncertainty inherent in climate change.

The cost curve is a flexible tool that be tailored for decision-makers' specific local requirements. For example, the cost-benefit ratios of individual measures can be weighted to take into account the extent to which they help vulnerable populations or support the overall development agenda of a location. (See Box: Tailoring the cost curve.)

Given the diversity of the hazards and development stages represented in the test cases, this finding would suggest that decision-makers in most locations are likely to have a set of viable and cost-effective measures available to them to address the bulk of their total climate risk to 2030.

For any given location, it is possible to identify the cost-benefit ratio of all selected infrastructural, technological, behavioral, and risk transfer measures. Given the highly local nature of the test cases, comparison across them in terms of absolute percentage of loss averted is of limited value. Nonetheless, →

TAILORING THE COST CURVE

Cost-benefit analyses, and the cost curve that represents them, can be tailored to requirement. For example, the cost-benefit ratios of individual measures can be weighted to take into account the extent to which they help exceptionally vulnerable populations, or to which they fit with the overall development agenda of a location. They can also be made more flexible: for example, a range of cost curves can be produced for a range of expected loss figures. Finally, they can be made more dynamic, for example by including a range of uncertainties (such as confidence intervals) for each cost-benefit ratio. This final modification would allow selection based on all possible – rather than likely – outcomes. For example, a measure with low uncertainty, or low risk of a very negative outcome, may become more attractive than a cheaper measure with a highly uncertain outcome.

it is striking to note that, across this incredibly diverse set of climate-sensitive locations, the test cases found that a minimum of nearly half of all expected loss can be averted through cost-effective adaptation measures.

PRIORITIZING A PORTFOLIO OF MEASURES

The cost-benefit analysis described above provides a fact base for decision-makers as they assemble a portfolio of prioritized measures to address their location's climate risk. This prioritization exercise will by necessity be a complex one requiring considerable judgment from decision-makers, and taking into account a range of considerations, of which the cost and impact of the measures are only a starting point. The relative ease of implementation of the measures in the portfolio will be a further consideration. And decision-makers will need to ensure that portfolio addresses the location's full range of climate risk – not only moderate change (for example in rainfall reduction or wind speed increase) but also variability and extreme events.

Importantly, the prioritization of adaptation measures will also be driven local policy goals and constraints whose considerations are quite different from minimizing financial costs and maximizing economic benefits. For example, a decision-maker may set out to minimize the loss of lives, or to protect the economy against damage caused by very extreme events (such a one in 10,000-year flood) – regardless of the cost-efficiency of the measures needed to achieve these outcomes. Such policy objectives should at a minimum be taken into account qualitatively during the decision-making process. Alternatively, they can be incorporated into the cost-benefit analysis by selecting the most efficient measures which realize the set objectives: as a result, cost-inefficient measures could also be included in the prioritized portfolio of climate-resilience measures.

Finally, the priorization process will, in addition to adaptation measures, need to consider measures that minimize the ongoing damage after a climate event, such as national disaster funds and emergency preparedness programs.

While this initiative focused on developing and testing the analytical tools required to assist decision-making, several cases also considered how a prioritized portfolio of measures might ➔

CALCULATING COSTS AND BENEFITS OF ADAPTATION MEASURES

Selected adaptation measures are assessed by calculating the net present value of the stream of costs and benefits for each measure over time, where benefits are equal to the loss averted compared to today's climate scenario, following a sequence of six steps.

1. **Determine the discount rate**. In the test cases, we used local government infrastructure-related decision discount rates. While different discount rates limit the ability to compare results in terms of the measure cost benefits, it is important to align the discount rate locally to ensure appropriate comparison with tradeoff decisions. Given our 2030 timeframe, the government investment discount rate usually is preferred to a more long-term social discount rate.

2. **Gather cost, benefit and expected useful lifetime data on each measure**. This step prepares a bottom-up calculation of the present value of costs and benefits of implementing the measure. This includes up-front expenditures, operating costs (for example, labor and maintenance), asset growth, extent of coverage or penetration (for example, the number of houses to be protected), and value of location, assuming both current and future use. This last component is primarily relevant to agricultural settings, where significant revenue may be at risk. In the test cases, we assumed that costs would grow at inflation. In some cases, we assumed that these costs would be financed – which results in an annualized cash flow similar to an annuity. For those measures that have a lifetime longer than 2030, we calculated a terminal value in 2030 terms and discounted it back following a standard net present value approach.

3. **Define the scope of the measure by determining the maximum potential** of implementing the measure in the local context. The total costs and averted loss will depend on the extent of the measure's implementation. For example, if only 50 percent of a crop can be drip irrigated, then assuming 100 percent penetration rate would skew the results.

4. **Calculate costs of each measure**. Based on the bottom-up assessment, we calculated capital expenditures (CAPEX), operating expenditures (OPEX), and operating expenditure savings (OPEX savings) compared to current approach – again mostly applicable to agricultural settings. If OPEX savings are available for the measure, a negative bar may appear on the adaptation cost curve.

5. **Determine if additional benefits from societal revenue upside is possible**. In some cases, implementing an adaptation measure will have economic benefits in addition to reducing the loss from the climate risk. For example in agriculture, most measures have a significant impact on yield (in the order of 20 percent, in the Maharashtra case) and therefore provide additional societal revenue upside. In our test cases, we assess societal revenue for agriculture and energy sectors.

6. **Calculate cost-benefit ratio** based on net present value of the streams of costs and benefits over time (including terminal value) in 2008 currency. This provides the y-axis location of the measure on the adaptation cost curve.

PRIORITY ACTIONS TO PROTECT INDIAN AGRICULTURE FROM DROUGHT

Maharashtra, like many other parts of India, faces the risk of drought from erratic rainfall patterns – drought that has historically caused severe disruption to agriculture and caused disproportionate harm to the millions of poorer people engaged in small-scale farming. The test case identified a wide range of measures whose introduction or wider use could protect agricultural production – and farmers' incomes – from drought. These included expanded drip and sprinkler irrigation; drainage construction; watershed management (for example, through afforestation and grass seeding); improved soil techniques; integrated pest management; crop engineering; and insurance.

A cost-benefit exercise (Exhibit 21) found, in principle, that Maharashtra can prevent much of its expected drought loss to 2030 through measures with relatively low cost. And for most of the measures identified, the economic benefits – primarily in the form of growth in the value of agriculture – exceed or closely approximate the costs. Although detailed cost benefit assessment was conducted on all of these measures, some of them are already planned by the national government and therefore included in the baseline growth assumption and not in the final cost curve that is focused on future investment decisions. See India test case appendix for more detail.

Overview of agriculture measures assessed – India test case

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Measure	Cost/benefit $/$	Cost $m	Benefit $m	Loss averted $m
Drainage systems (rf)[1]	-2.1	-80	74	3
Soil techniques	-0.2	-197	1,109	21
Drainage systems (ir)[2]	-0.2	-74	447	16
Irrigation controls	0	14	1,438	59
Drip irrigation	0	139	7,978	547
Crop engineering (ir)	0.1	81	1,155	64
Integrated pest mgmt. (ir)	0.1	49	551	36
Integrated pest mgmt. (rf)	0.1	146	1,374	91
Sprinkler irrigation	0.1	285	3,280	225
Watershed +rwh	0.1	534	4,545	312
Last mile irrigation	0.3	1,553	5,467	227
Rehab. of irrigation systems	0.4	966	2,733	113
Ground water pumping	0.7	1,837	2,733	113
Crop engineering (rf)	0.7	271	1,384	35
Planned irrigation projects	0.7	8,987	12,027	499
Canal lining	0.8	16	20	1
Insurance	1.0	1,035	1,035	1,036

1 Rf = rain fed agriculture
2 Ir = irrigation fed agriculture

From this shortlist of measures, a prioritized portfolio of action steps was created, with early action focused on the measures that are most affordable and most likely to be implemented successfully (Exhibit 22).

As in most of the other cases, risk transfer measures – such as index insurance for small farmers – proved to be a necessary complement to prevention measures in the case of severe, infrequent drought. As Exhibit 23 shows, risk transfer measures would address a large part of the loss in once in 50 year droughts, whereas prevention measures would address the bulk of the risk from more-frequent, less-severe events.

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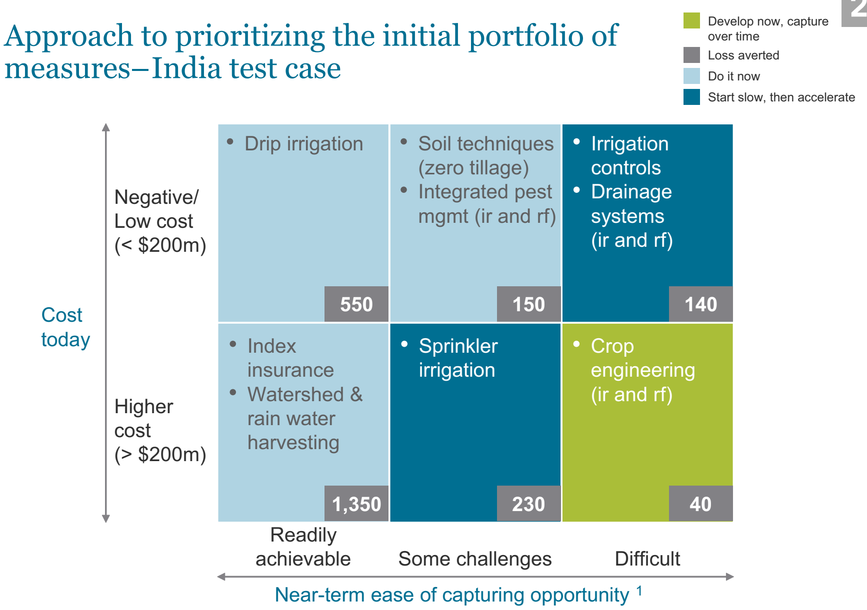
Approach to prioritizing the initial portfolio of measures–India test case



1 Based on financing issues, regulatory support, agency issues, entrenched behavior, supply constraints and technological readiness

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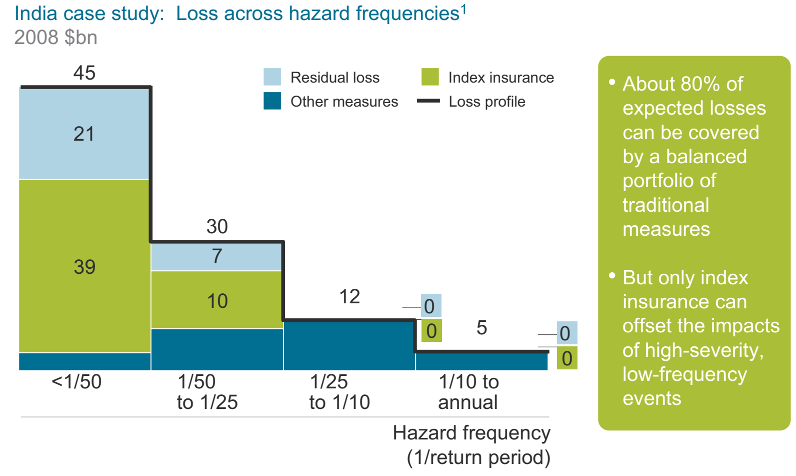
Approach to prioritizing the initial portfolio of measures – India test case



1 This is loss before adjusting for frequency range. Annual expected loss is area under the curve

be constructed from the findings. (See box: Priority actions to protect Indian agriculture from drought).

BEYOND COST-BENEFIT ANALYSIS – DECISION-MAKING IN A RISK INFORMED ENVIRONMENT

Cost-benefit analysis provides a powerful tool to identify the most attractive adaptation measures based on an economic assessment. However, as discussed above, this approach has some limitations and provides just one input into a multi-criteria decision-making process. One of the most significant limitations of cost-benefit analysis is its assumption that decision-makers are risk-neutral and make choices based primarily on economics – and would therefore tend to prefer measures whose economic benefits outweigh their costs. As we emphasize throughout this report, decision-making is in fact based on many other factors, including risk appetite, qualitative impacts and policy targets. Take as an example the Delta Committee in the Netherlands, which has specified that dikes in some parts of the country be built to withstand a 1-in-10,000-year event. The high level of protection is likely determined politically considering local experience and risk-taking appetite, rather than purely economically.

To improve their usefulness, cost-benefit analyses can be modified to take into account non-economic factors. In the test case on Samoa, for example, we extended our methodology to account for the risk aversion of the decision-maker. The key input in performing this kind of analysis is an explicit policy target. In the Samoa case, we considered a policy target formulated as the share of coastal flooding risk Samoa is willing to shoulder instead of transferring it to capital markets via insurance or averting it through adaptation measures. For the purposes of testing our methodology, we assumed that maximal acceptable loss during a 250-year event was 5 percent of GDP. Note that, in reality, the selection of such a threshold is a subjective function. It must be determined on a case-by-case basis based on a set of qualitative or semi-quantitative criteria such as the resilience of the economy to negative shocks.

Once the policy target has been established, the modified methodology consists of looking at the most cost-efficient measures to realize this target, including measures that are

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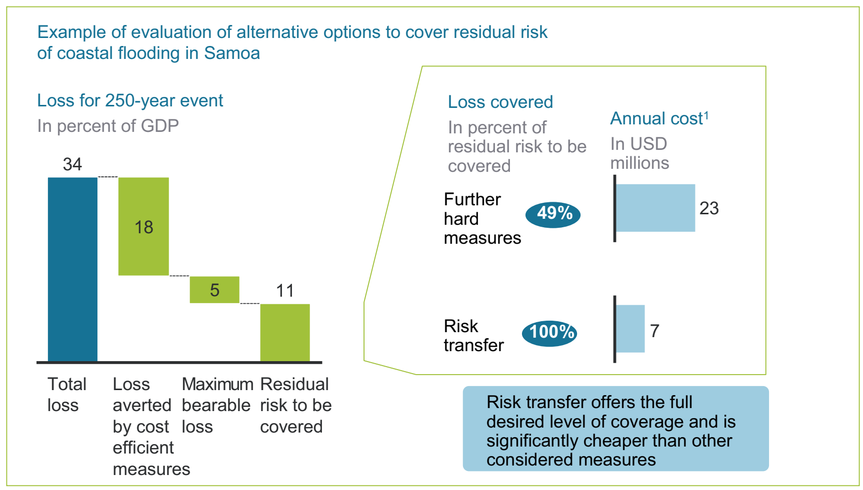
Risk transfer is the most efficient way of providing additional coverage for low-frequency events



1 Estimate based on Swiss Re estimate

not cost-efficient according to risk-neutral criteria – that is, measures with a cost-benefit ratio greater than 1. It is also useful to note that policy targets change and are re-evaluated as more information and experience is gathered. For example in Florida, building code regulations have been strengthened in recent years, in response to the severe losses caused by Hurricane Andrew in 1992.

In Samoa, the standard cost-benefit analysis showed that 54 percent of the damage expected to occur in 2030 during a 250-year coastal flooding event can be averted by a set of cost-efficient adaptation measures. The residual risk for a 250-year event thus amounts to 12 percent of GDP. Of the other available adaptation measures – with cost-benefit ratios of greater than 1 – risk transfer presented the most cost-efficient solution by being at the same time cheaper and more effective than the other measures considered (Exhibit 24). ➔

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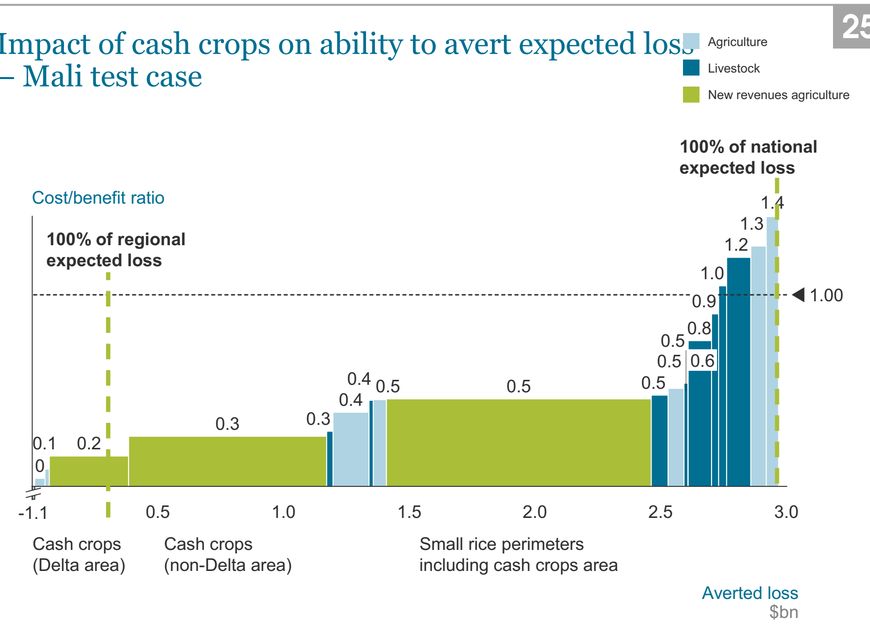
Impact of cash crops on ability to avert expected loss – Mali test case



CLIMATE RESILIENCE BOOSTS ECONOMIC DEVELOPMENT

An ingoing belief of the Working Group on undertaking the Economics of Climate Adaptation initiative was that rational measures to improve climate resilience are in many cases also effective steps to strengthen economic development. The findings from the test cases showed this to be true, and underlined the view already articulated by other studies[27] that many climate resilience or adaptation measures can be integrated with economic development strategies.

BEYOND LOSS AVERSION – BUILDING NATIONAL WEALTH

The test cases also highlighted a particular opportunity for developing countries to shape integrated climate resilience and development strategies, not only to avert loss but also to achieve substantial improvements in national wealth. In Mali, for example, the cost-benefit analysis for measures to address climate risk showed that one key measure – the development of new areas of cash crop production – could, if implemented in just the Mopti region that was the focus of the case, avert the entire country's expected economic loss from climate change and bring in some $2bn in additional annual revenue (Exhibit 25).

HEALTH: EXTENDING THE COST-BENEFIT APPROACH BEYOND ECONOMIC IMPACT

Several of the test cases also demonstrated the positive impact that climate resilience measures can have on health. In Guyana, putting in place basic flood-proofing measures and emergency response capabilities – key measures to address climate risk – would also significantly reduce mortality. In Tanzania, basic measures to improve water availability – such as rainwater harvesting and construction of wells, boreholes and tanks – would prevent tens of thousands of cases of trachoma annually, at an average cost of less than $10 per case prevented. The regions with the greatest burden of climate-sensitive diseases are also the regions with the lowest capacity to adapt to the new risks. In these places, disease is most often the result of poverty, overpopulation, lack of access to fresh water, malnutrition, and lack of sanitary facilities, all of which will be exacerbated by climate change. Essentially, the change in temperature and precipitation will affect the disease vectors. We reviewed local precipitation and disease occurrence data to test the local Tanzania hypothesis of a correlation between the two.

We conducted a test of the cost-benefit methodology and adjusted it to compare the costs and public health benefits (in terms of number of cases treated or prevented) of a range of measures to combat trachoma and other diseases in Tanzania. The notion of "loss averted" benefit, originally conceived as an economic measure, required adjustment when applied to public health. Although cost is obviously not the only criterion in assembling a public health strategy, this exercise provides a comparison of the cost-effectiveness of various measures, as input into such a strategy (Exhibit 26).

UNLOCKING FUNDING

It is important to note that integrating climate resilience measures with economic development strategies is also likely to help unlock the funding required both to address existing climate risk and adapt to climate change. The UNFCCC recently estimated that by 2030 the world will be spending an additional $36–$135bn each year to address impacts associated with climate change – and that $23–$55bn a year in additional

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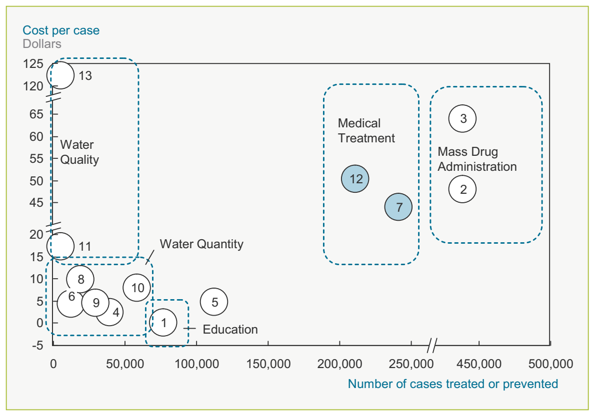
Adaptation measures to treat and prevent trachoma – Tanzania test case



Trachoma Measures

1. Educational program to encourage face cleaning
2. Mass administration of antibiotics to entire communities- donated drugs
3. Mass administration of antibiotics to entire communities- purchase drugs
4. Build basic covered wells with pipes
5. Build ventilated pit latrines
6. Rainwater harvesting with 1,000L sand and cement
7. Targeted administration of antibiotics to active cases
8. Rainwater harvesting with 20,000-45,000L reinforced rainwater harvesting tank for schools and other public buildings
9. Rainwater harvesting with 2,500L sand, cement, chicken wire
10. Build 100 MM boreholes + pump + engine + 40,000L holding tank + distribution pipes
11. Mechanical filtration of water
12. Trichiasis surgery to prevent blindness
13. Chemical filtration of water

investments and financial flows will be needed to fund adaptation in the developing world[28]. Regardless of the size of the adaptation fund likely to be agreed upon in Copenhagen, the majority of this funding will need to come from the private sector. Climate resilience measures with demonstrated net economic benefit, integrated into coherent development strategies, are much more likely to attract private sector investment – and trigger valuable new innovations and public-private partnerships.

Multilateral and development funding will, of course, also have an important role in shaping climate-resilient development paths, and a coherent framework for assessing climate risk and evaluating the costs and benefits of measures will help countries and international institutions to allocate and apply this funding more efficiently.

"PERISHABLE" INVESTMENT IN CLIMATE RESILIENCE

An important note about the timing of investment in strengthened climate resilience: Even though there is still considerable uncertainty about how climate change will impact local economies, the findings from the test cases suggest it is critical that decision-makers take early action to incorporate climate resilience into economic development strategies.

There may be a temptation to ignore large risks with a perceived low probability, or simply to "wait and see" – but as the studies show, much of the climate risk that societies face is from known, historical weather patterns; and science-based climate change scenarios raise a plausible prospect of significant additional risk to 2030. Indeed, well-targeted, early investment to improve climate resilience is likely to be cheaper and more effective for the world community than complex disaster relief efforts after the event.

Many of the most effective climate resilience measures will require significant lead times before they can be put in place; and investment decisions in infrastructure and technology typically have long depreciation periods. A clear view of a location's total climate risk and of the costs and benefits of the available adaptation measures will allow leaders to make such decisions with a better sense of priority. ❍

CHAPTER 3: TAKING CLIMATE-RESILIENT DEVELOPMENT FORWARD

Assessing and addressing climate risk: lessons learnt from the test cases | Steps to implementing a comprehensive strategy for climate-resilient development

The findings discussed in the previous two chapters show that our societies have an opportunity to put in place workable, cost-effective programs that greatly improve their levels of climate adaptation – and that in so doing, boost sustainable development.

This chapter highlights several important lessons learnt from the test cases on how decision-makers can best assess and address the climate risk facing their economies and societies – and on how the framework piloted in this study can be expanded. This chapter also discusses the tactical steps that decision-makers can take to implement the framework at broader scale in their own countries, regions and cities – thus embedding sound adaptation choices in their economic development paths.

$26-135bn

The UNFCCC recently estimated that by 2030 the world will be spending an additional $36–$135bn each year to address impacts associated with climate change.

ASSESSING AND ADDRESSING CLIMATE RISK: LESSONS LEARNT FROM THE TEST CASES

Five main lessons emerged from the initial application of the climate risk framework to the eight local test cases.

LESSON 1: ACROSS DIVERSE CLIMATE RISKS AND IMPACTS, A COMMON RISK FRAMEWORK APPLIES

The Working Group's objective in conducting this initiative was to create a robust, replicable framework to assess and quantify the climate risk faced by an economy and to prioritize a set of measures to address that risk. The initial version of that framework was piloted on a trial-and-error basis across the test cases. Having reviewed the results of this exercise, the Working Group is confident that the framework – specifically its core quantitative analyses – will indeed apply to virtually any country, region or city, as well as to public and private sector organizations with large asset bases exposed to climate risk. For a great variety of settings and climate risks – from local rain-driven flooding in a mixed urban and agricultural setting such as Guyana, to drought-related health impacts in a low income rural region such as central Tanzania – decision-makers can derive value from the loss model and cost-benefit evaluation of adaptation measures that the framework provides.

The implication for all decision-makers is that it is possible to undertake a focused, solutions-oriented climate risk assessment and identify a portfolio of high-impact climate resilience measures with a detailed understanding of their costs in a short space of time.

It is important to emphasize, though, that applying the risk management framework requires a broad spectrum of information. In the test cases, mining this information required significant effort, time and access. In Maharashtra, India, for example, we assessed over 100 years of detailed monthly rainfall to determine the 1-in-10 and 1-in-25 and 1-in-100 year events. In China, we needed to identify the specific months of precipitation that would affect the crop yield the greatest. To do this, we conducted a regression analysis between the drought-covered areas over monthly, seasonal and annual precipitation records at the provincial level using data from 1983 to 2000. (See the Methodology Guide in the Appendix for further detail on information sources and approaches.)

LESSON 2: ANALYTICAL APPROACHES TO ADAPTATION ARE POSSIBLE – EVEN IN LOCATIONS WHERE DATA IS SPARSE

In several of the locations assessed in this study, climate and economic data was sparse. On the face of it, this made the task of quantitatively assessing climate risk and adaptation measures a challenging one. In all these cases, however, we were able to work with local experts and officials both to develop a robust climate loss model and to calculate economic cost benefits for a range adaptation measures.

In Guyana, for example, the historical data on rainfall and correlation to flooding was limited to a few events, making it difficult to assess the climate hazard component of the loss model. However, based on good flood height measurement data from a recent flood widely believed to be a 1-in-100 year occurrence given the historical record, we were able to build a flood map predicting the height of flooding in a certain location based on localized rainfall level. Local experience on the correlation between rainfall and flooding, as well as historical understanding of flood patterns provided further detail and supported the assumptions required.

Our experience further suggests that expert academic support will be required to conduct the key analyses, particularly to quantify climate risk in developing countries. In Mali, we partnered with agriculture and livestock experts to model the vulnerability of the primary crops to changes in precipitation.

Leveraging existing work on the current vulnerability of crop yield to climatic conditions significantly increased the speed at which we could assess future climate impacts. In Tanzania, local health and precipitation data allowed calculations for initial correlations between disease incidence and prevalence. Local healthcare expertise was critical to understanding these correlations, and contradicted some of the beliefs of external researchers.

LESSON 3: ADAPTATION REQUIRES ANALYTICAL TECHNIQUES THAT REFLECT THE LOCAL NATURE OF RISK

The analytical tools at the heart of the framework described in this report – an expected loss model, and bottom-up cost-benefit analysis – are most effective in a local setting. In some countries, climate risk is fairly homogenous across different geographies – for example, the risk of sea level rise for a small island, or the risk of broad climate zone shift. By and large, however, risks such as flooding, storm damage and drought vary greatly across different regions and cities – and very often across the districts and suburbs within them.

It is tempting to scale up local results to the national level, potentially as input into adaptation funding discussions. However, such scaled-up results do not reflect regional differences in hazards, value and vulnerability in sufficient detail to inform robust adaptation decisions. Therefore, the expected loss approach to quantify climate risk is most effective when applied to the local setting. For a national study, such local assessments would need to be replicated across multiple regions. Alternatively, because adaptation is so extremely local, the lesson for a national decision-maker such as a finance minister is that the portfolio of national actions must take into consideration local conditions following a prioritization exercise as suggested by our methodology.

To illustrate the difficulty of scaling up local results consider the cost estimates developed in the test cases in Guyana and India. In Guyana, the risk of rain-induced flash flooding exceeding the capacity of man-made urban and agricultural drainage is fairly homogenous across the country. However, further analysis on how flooding varies in different settings – especially those ➔

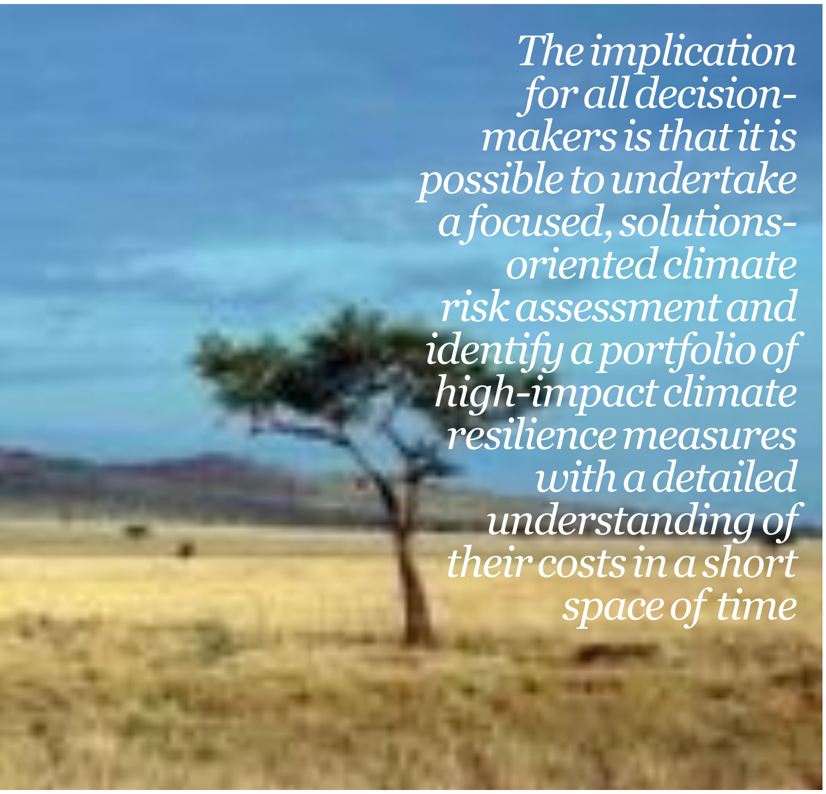
with advanced sea walls and pumping stations – would be invaluable to achieve a better estimate of national annual expected losses from flooding. In India, we attempted to scale up the results of the Maharashtra test case to determine the required annual national capital spend to address drought risk. However, the agricultural differences in terms of rainfall and crops – even across districts defined as drought-prone – turned out to be so significant that the figure arrived at, $25bn a year in 2030, could be no more than a top-down estimate. A bottom-up approach, assessing India's drought risk and the costs of addressing it state by state, would produce a much more reliable picture.

LESSON 4: AN INCLUSIVE PROCESS IS NEEDED TO DEVELOP A LONG-LIST OF ADAPTATION MEASURES – BUT PRIORITIZATION IS IMPORTANT IN MOVING RAPIDLY FROM IDEAS TO ACTION

Given adaptation's development context, the list of possible measures to address current and future climate risk is in theory almost infinite. While an exhaustive list of measures that passes feasibility and applicability criteria is important, developing a list of thousands of options would be excessively time-consuming – even for the most well funded public sector endeavors. In a given time period, the objective is to quickly develop a long-list of measures and ensure that every idea that makes sense to the experienced local stakeholders is on a shortlist for quantitative assessment. The cost-benefit approach forces a discipline of ranking measures by their effectiveness against the expected loss, allowing a rapid shift from a list of ideas to a set of potential actions.

In identifying measures to shortlist for quantitative analysis, key success factors include gathering a wide range of measures spanning several categories of actions for the initial long-list; prioritizing adaptation measures qualitatively based on feasibility; and verifying this selection with local stakeholders and experts. All these steps take place before the cost-benefit analysis begun.

In developing the long-list of measures, engaging with local NGOs and the informal sector – in addition to public and private sector leaders – is critical to developing a robust portfolio. On the other hand, seeking to attain every possible option is not an effective approach. Some level of expert opinion helps in highlighting measures for which quantitative evaluation is warranted. In Florida, for example, we interviewed a range of experts across fields including NGOs, climate scientists and private and public sector engineers to identify the shortlist of measures that have proven successful to date in addressing hurricane risk. In developing the long-list of measures for the Mali test case, we conducted a series of workshops, both with the leaders, administrators and experts engaged officially in the NAPA process, and with local farmers in the Mopti region.



LESSON 5: CLIMATE RISK ASSESSMENT ALLOWS DECISION-MAKERS TO VIEW DEVELOPMENT CHOICES THROUGH A NEW LENS, LEADING TO DIFFERENT SEQUENCING AND PRIORITIZING OF ALREADY-KNOWN MEASURES

Our experience in identifying, prioritizing and quantitatively assessing adaptation measures highlights the already well-understood notion that such measures overlap with development actions; in fact, all the measures assessed in the test cases are already-known development steps in in use in the locations concerned. Perhaps the most valuable contribution of the framework described in this report is the fact that it allows decision-makers to view and consider development measures through a climate risk lens – one that quantifies both the impact of climate on the economy, and the cost and economic benefit of measures to minimize that impact. This climate risk lens allows decision-makers to sequence and prioritize known development measures according to their efficacy in addressing climate risk. In Mali, for example, local farmers and national leaders already encourage optimum crop mixes and cultivation of the most ideal agricultural "bread baskets". They currently utilize water supply and efficiency measures such as afforestation and reduced tillage soil techniques. A climate risk assessment sheds new light on these and other measures: for example, significantly greater scale and priority is required for measures that deal with chronic shortages of water. In Mali, the climate risk lens reveals that measures such as low tillage, solar pumps, canals, and livestock vaccines is have the potential to avert the majority of the country's expected annual climate-related loss, but the penetration and implementation challenge to achieve this potential is daunting. It would therefore be a priority for government, NGOs and development organizations to build the institutional and local capacity needed to overcome these challenges.

The analyses profiled in this report essentially bring robust data and insights on climate risk to the already complex decision-making environment. The starting point for development planning is often a specific, urgent question, such as "How can we maximize agricultural productivity?", "How can we reduce reliance on food imports?", or more generally, "How can we enhance economic development in our region?". As the global climate continues to change, these questions will become increasingly intertwined with those of adaptation. In fact, it could be argued that no robust development planning policy for the next 20 or more years can be created without assuming a radically changing environment and incorporating this climate risk into the decision-making process.

Lastly, one cautionary note. It is important, while assessing the baseline economic growth of a location, to consider current economic development initiatives that overlap with the measures appropriate for an adaptation strategy. Essentially, the scope of measures assessed and baseline economic growth assumptions need to consider current plans. While our assumptions of baseline economic growth projected historical economic growth rates, applied expert consensus on GDP growth, or tied agricultural sector output to population growth, we did exclude from our value growth assumptions those measures already "counted" in the location's current development trajectory. For example in India, many of the larger-scale irrigation projects that cost-benefit analysis suggests would be the most effective in reducing future losses from drought impact are already incorporated into the national development plans and therefore excluded from assessment. In India then, although we quantified the cost-benefit of all the measures, we assumed last mile irrigation, rehabilitation of irrigation systems, ground water pumping, and canal lining adaptation measures are part of the necessary activities required to achieve the baseline growth of agriculture value. ➔

STEPS TO IMPLEMENTING A COMPREHENSIVE STRATEGY FOR CLIMATE-RESILIENT DEVELOPMENT

In all the locations studied, a cost-effective portfolio of known and tested measures, informed in part by the analyses profiled in this report, should in principle be available to address a significant portion of the climate risk identified through 2030 – even in a scenario of high climate change. The same is likely to be true in many other countries, regions, and cities. In a relatively short space of time, a similar approach – incorporating risk identification and quantification as well as evaluation of the cost-effectiveness of adaptation measures – could be applied in broader national or local efforts to strengthen climate-resilient development.

The approach described in this report – and outlined in detail in the Methodology Appendix – would produce the essential analysis and fact base for inclusion into a broader effort to incorporate climate risk into development decision-making. The data and insights generated by the framework should prove particularly valuable in development planning processes, providing a fact base on how development strategies can best account for climate risk and integrate climate adaptation measures.

However, changing economic development decisions will require a significantly scaled-up analytical effort and incorporation of specific actions to address traditional implementation barriers, including organizational and institutional bottlenecks and financial constraints. This broader, scaled-up effort is likely a journey of several years requiring actions across the public, private, informal, and social sectors.

The following section lays out a sequence of seven steps that decision-makers can take in designing and implementing a broader effort to strengthen their economies' climate resilience.

STEP 1: START WITH A COMPREHENSIVE APPROACH AND OBJECTIVE

To develop a comprehensive approach to climate-resilient development, a stakeholder-driven effort is required at the country, region or city level, assessing all relevant risks from a local base. The approach would ideally be an official process led by a senior government decision-maker, with significant engagement from the private sector, NGOs and academics building on the NAPA efforts. The objective of this more comprehensive approach could be a policy framework for climate-resilient development, providing a broad policy wrapper for the full range of measures. Such an approach would also identify financing solutions; define new types of partnership and evolving roles for government; and understand what policy and other changes are needed to overcome barriers to implementation. The approach would actively engage local experts and all relevant stakeholders, and draw on existing literature – yet it should be sure to generate fact-based conclusions, rather than assuming that commonly held beliefs about the climate hazards facing a location are correct.

STEP 2: PRIORITIZE HAZARDS AND LOCATIONS

The test cases profiled in this report prioritized one or two hazards per location, and in some cases one or two particularly vulnerable regions or economic sectors. This highly focused scope was driven by our purpose of testing the methodology across multiple locations in a short space of time. But even if time or resources were not a constraint, not all hazards are relevant to every location in the world and not all sectors are particularly vulnerable, or important for supporting livelihoods. Conducting a more comprehensive effort would still require a prioritization approach in order to focus the analysis, based on the question: "Where and from what is the country most at risk?" The loss assessment should still begin with an assessment of the historical and current climate risks of the location under study – critically understanding which areas are most affected by the hazard, and what the distribution is of vulnerable people and economic activity. A comprehensive national study could assess the climate risk of an entire country but still focus the analysis of adaptation measures on the hazards most relevant and sectors most vulnerable for each specific area. For example, a country study in Tanzania would not only address drought impacts on health and agriculture in the central regions, but also increased rain and storm-driven flooding on the coastal communities.

STEP 3: RECOGNIZE THE UNCERTAINTY ABOUT FUTURE CLIMATE – BUT DO NOT BE FROZEN BY IT

A comprehensive approach should acknowledge the debate around climate science, and the differences in local climate

It could be argued that no robust development planning policy for the next 20 or more years can be created without assuming a radically changing environment and incorporating this climate risk into the decision-making process

projections in particular, to develop a range of meaningful scenarios that reflect the uncertainty about the future impacts of climate change. Building scenarios on future climate reflects the notion that climate is the variable with the most uncertainty. The inclination, in some cases, is to assume the uncertainty is too great to allow specific actions, but it is important to remember that a climate risk assessment exercise is not predictive in nature, but rather designed to understand the range of possible outcomes to help incorporate future climate risk into decisions today. Building scenarios based on existing science and being explicit about the range of uncertainty is critical: such scenarios allow potential future climate-related loss to be quantified. One way that decision-makers can help solidify the range of possible climate outcomes is to set up an independent, academic review board to set these scenarios.

The experience of the Tanzania test case illustrates the complexity involved in developing climate scenarios. For Tanzania, the general circulation models suggest an increase in average precipitation in the 2030 timeframe, yet national power producers that rely on hydropower have plans to diversity their generation sources due to anticipated increase in droughts in the central region where their reservoirs are located. This apparent conflict is a question of understanding the granularity of data. Regional climate models indicate that Tanzania will face two hazards – more rain and storms on the coast, but greater drought in the central regions. Engaging local experts on the regional climate differences enables a prioritization of drought impact on hydropower generation.

STEP 4: FOR COST-EFFECTIVE PRIORITY MEASURES, DEFINE CURRENT AND TARGET PENETRATION

Working through a cost-benefit prioritization methodology results in a set of specific and concrete measures. As discussed above, these measures are not new, but they are prioritized in a new way given their expected net benefit in addressing climate risk. An assessment of the current penetration, expected growth, and targeted level of penetration of these measures will help crystallize the focus of a climate-resilient development strategy – will indicate where funding can be invested for greatest impact.

The Indian agriculture test case illustrates how defining the target penetration of a particular measure can have a →

significant influence on that measure's impact. Consider the example of watershed management programs – efforts to improve the quality of cultivated land through afforestation, dedicated pasture. These programs have been proven to increase yield by 25 percent over a 3-year implementation period, and reduce economic losses by 50 percent during 1-in-10 year drought event. However, the current penetration in Maharastra is less than 2 percent of total land area under cultivation: although these programs are very promising, but it is difficult to determine what their future scale might be, and therefore their potential in addressing Maharashtra's overall drought risk. To better understand this potential, the test case conducted interviews with some 50 farmers in Maharashtra, as well as with experts, the National Bank for Agriculture and Rural Development, the Federation of Indian Chambers of Commerce & Industry, NGOs and government officials administering the programs locally. These interviews suggested that rapid expansion of watershed management programs was possible, to a target of 10 percent of total cultivable land by 2030 – equivalent to 2,000,000 hectares. Achieving this penetration, though, would require a series of implementation steps including improving the capacity of NGO administrators and continued growth in government technical assistance and training.

STEP 5: FOCUS ON ADDRESSING TRADITIONAL DEVELOPMENT IMPLEMENTATION BOTTLENECKS

Climate risk will, in most cases, deepen current development challenges, such as water scarcity and drought, flooding, storms, coastal and ecosystem degradation, disease and mortality, and agricultural productivity. Achieving climate-resilient development will entail grappling with many of the same bottlenecks historically faced in implementing development efforts. These include setting an appropriate policy framework (for example, clarifying land right issues in Mali), institutional capability, basic infrastructure, and access to finance.

There are several existing tools that can assist decision-makers in overcoming these bottlenecks in the context of adaptation. For example, the Adaptation Policy Framework (APF)[29] was developed to support national planning for adaptation by the United Nations Development Programme (UNDP) and provides guidance on how these obstacles and barriers to mainstreaming can be overcome.

Addressing organizational issues at the local level will be a further key requirement for successful implementation of climate-resilient development strategies. Based on our experience in the test cases, few locations currently have the appropriate units or authorities in place that are sufficiently prepared, resourced, or empowered to lead and implement such strategies.

STEP 6: ENCOURAGE SUFFICIENT FUNDING FROM THE INTERNATIONAL COMMUNITY

According to current estimates, the magnitude of the official development aid available today is small in comparison to the ultimate cost of developing under increased climate risk (See Methodology Appendix). Allocating international funding may help ensure that a global deal on emissions is completed, but a majority of the costs of adaptation will likely be carried outside of international funding schemes. Incorporating an assessment of future climate risk into countries' current development decisions is the ultimate goal in addressing the adaptation challenge. International funding could encourage this outcome through investment in technical skills, policy and planning, and knowledge dissemination at the country level.

STEP 7: RECOGNIZE, FACILITATE AND MOBILIZE DIFFERENT ROLES FOR EACH STAKEHOLDER

In any such process, aligned and coordinated engagement with all stakeholders will be key – not only with NGOs, academics and government agencies, but also with people living and doing business in the area under study: their own experience in living with and addressing climate risk will contain a wealth of information on climate risk and solutions for climate resilience. An effective local assessment of risks and identification of measures must be grounded in current knowledge – and is the foundation for successful implementation of a local adaptation and development strategy.

It is also clear that the implementation of adaptation solutions will be led, financed, and scaled up by different actors depending on the nature of the measures. Government involvement will be required for larger-scale infrastructure measures, such as major irrigation efforts (development of the Mali Delta is one such example). Smaller-scale measures such as watershed

management are often best facilitated by NGOs in their local settings. International institutes also have an important role, offering expertise on issues such as crop engineering and meteorological analysis. Additionally, a positive enabling environment can be established by the public sector at multiple levels, leaving room for private sector participation.

Specific roles for particular stakeholders might include:

- National government: implement risk management policies integrated into economic development (for example, China's Ministry of Finance has integrated risk management planning with economic development planning)
- Sectoral government agencies: implementing, incentivizing, and regulating relevant strategies (for example, the Agricultural Development Ministry could incentivize appropriate irrigation technology in Mali)
- Local government: implementing local-level strategies (such as beach nourishment projects in Florida)
- Private sector: providing services and products that provide climate risk management benefits (such as insurance incentives for roof covers in Florida, or roof cover installation services)
- Individuals: disaster preparedness and community preparedness (a key factor, given that 80 percent of people rescued during a natural disaster are rescued by a neighbor). ❍

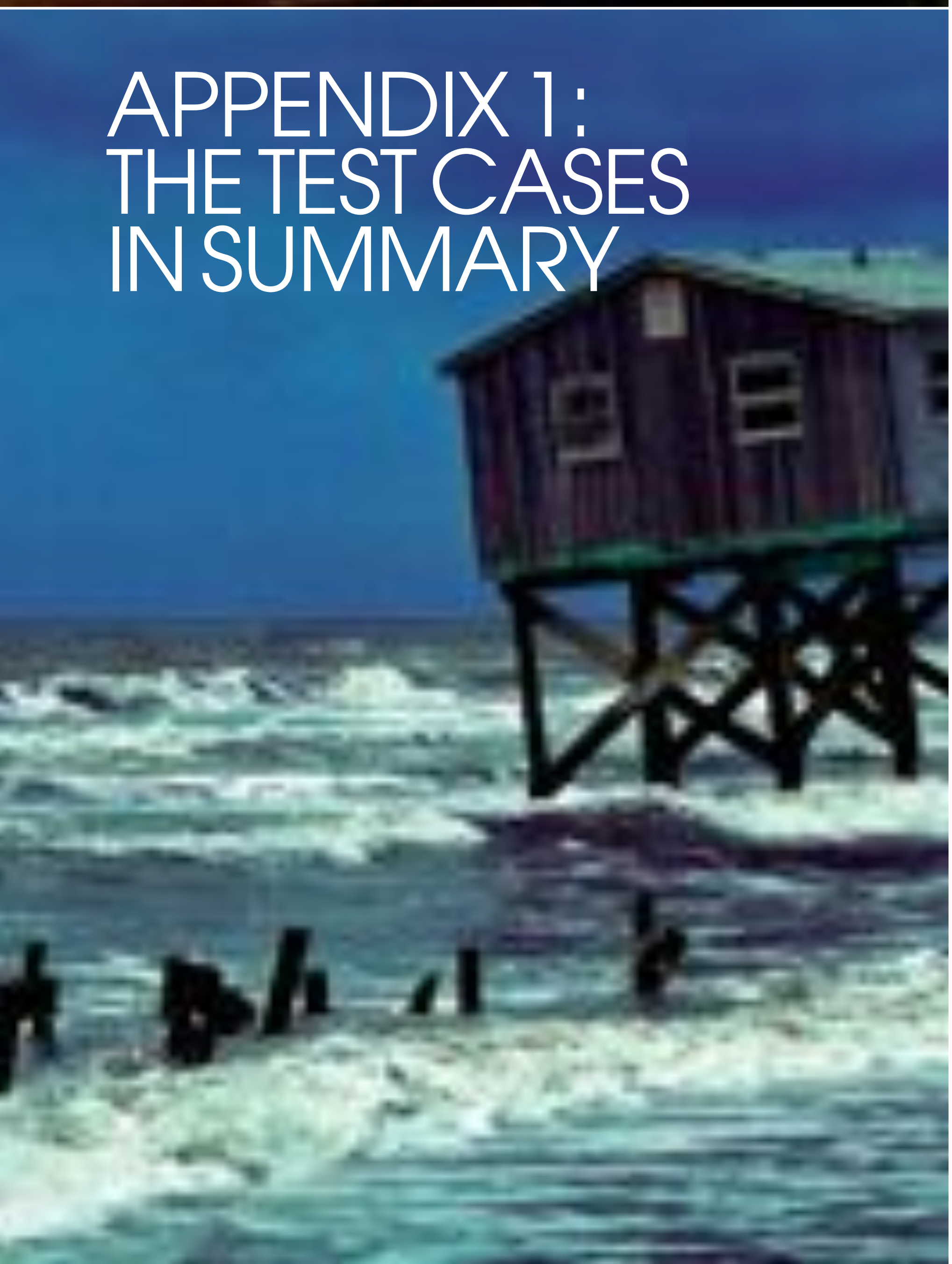
CONCLUSION

This report's focus has been on sharing a practical analytical toolkit to aid decision-making and resource allocation. But its purpose is broader: to make a contribution to shifting countries' development paths towards greater climate resilience.

Many of the world's economies are already poorly adapted to climate risk, and our historic pace of population and GDP growth could put ever more people and value at risk. All indications are that climate change could heighten this danger considerably. While adaptation does not replace the need for the world to set and achieve bold targets for reducing carbon emissions and slowing the rate of global warming, it does represent a crucial component of the global response to climate change.

Yet adaptation is also an opportunity – a prompt to operate our economies more efficiently and more consciously of the risks inherent in the climate forces around us. Humans are inherently adaptable: should we seize this opportunity, we will have the chance not only to protect ourselves and future generations from climate hazards, but also to shape more prosperous and sustainable development paths for all the world's people. ❍

APPENDIX 1: THE TEST CASES IN SUMMARY



Test case on North and North East China: focus on drought risk to agriculture | Test case on Maharashtra, India: focus on drought risk to agriculture | Test case on Mopti region, Mali: focus on risk to agriculture from climate zone shift | Test case on Georgetown, Guyana: focus on risk from flash floods | Test case on Hull, UK: focus on risk from multiple hazards | Test case on South Florida, USA: focus on risk from hurricanes | Test case on central Tanzania: focus on the impact of drought on health and power generation

This appendix provides brief synopses of the test cases. Each of these cases was conducted on the ground in the country concerned, drawing on local expertise and stakeholder engagement, and frequently building on existing efforts such as the NAPA process. Further detail on the specific calculations is available upon request from the Working Group to those interested in the assumptions and details of the approach in each country. While the test cases are not intended to provide the full input needed to develop national or local adaptation strategies, they do provide detailed, quantified assessments of some of the most significant climate risks faced by the regions and cities under study, along with thorough cost-benefit analysis of the measures available to address those risks. The test cases therefore provide useful input for stakeholder discussions on improving economies' climate resilience, and a foundation on which to build broader climate risk assessments.

The case findings are relevant to many other countries, regions, and cities across the globe. In particular, the test cases address the following groupings of climate risk, impacts, and geography.

RISKS TO AGRICULTURAL PRODUCTION FROM DROUGHT AND CLIMATE-ZONE SHIFT (CHINA, INDIA, AND MALI TEST CASES)

Agriculture is by definition highly sensitive to climate, and there is global concern about how climate change might impact food production. In the regions analyzed in these three test cases, agriculture is a vital economic sector at risk from significant loss in 2030 – from drought in the cases of North and Northeast China Heilongjiang, Jilin and Liaoning provinces, and Maharashtra state in India, and from the southward shift of the arid Sahara climate zone in the case of Mali. In all these cases, the climate change scenarios could significantly exacerbate the risks to already vulnerable agricultural sectors – with serious implications for food security and the farming communities' livelihoods. However, a key finding of these cases was that a portfolio of adaptation measures could avert the majority of the loss – and that such measures have the potential to strengthen economic development. The approach adopted to assess and respond to the "total climate risk" of these locations could be replicated in many other climate-sensitive agricultural regions.

RISKS TO COASTAL CITIES FROM FLOODS, STORMS, AND SEA LEVEL RISE (GUYANA, SAMOA, UK, AND US)

Worldwide, the population of coastal cities is growing rapidly despite their often high vulnerability to multiple climate hazards, including storms, flooding, and sea level rise. The test cases included four coastal population centers in very different settings – Georgetown in Guyana, the islands of Samoa, Hull in the UK, and three Miami-area urban counties in Florida, USA. Across all the test cases undertaken, Georgetown and Miami were the two with the greatest economic value at risk – reflecting a high concentration of asset value in climate-sensitive locations. Again, though, even such

relatively vulnerable cities have a portfolio of adaptation measures available to them that can avert the bulk of the loss they face. These measures span infrastructure improvements, steps to influence the behavior of residents, changes in urban planning and building codes, and risk transfer. The approach to assess the risks and identify these measures could be replicated in many other densely populated urban regions.

RISKS TO ISLAND STATES FROM SEA LEVEL RISE (SAMOA)

Some 70 percent of Samoa's villages lie along the coast, and one in three buildings is located below a 4 meter elevation, making the country and its people highly vulnerable to flooding from tropical cyclones. Sea level rise resulting from climate change, the focus of this case, could magnify this risk. It could also cause salt water to encroach into the fresh groundwater aquifer, compromising fresh water sources and threatening both human health and coastal agriculture. Even in a scenario of high climate change, however, the bulk of losses can be averted: cost-effective flood-aversion measures, for example, include planting a protective mangrove buffer, using mobile flood barriers, and requiring a minimum elevation for new buildings. The approach used to assess risks and identify such measures could be replicated in many other island settings.

BROADENING THE APPLICATION OF THE FRAMEWORK: RISKS TO HUMAN HEALTH AND POWER GENERATION FROM DROUGHT (TANZANIA)

The Tanzania case tested the broader applicability of the risk management framework that assesses "total climate risk" and applies a cost-benefit approach to evaluating adaptation measures. The case focused on two specific drought impacts that are of particular concern for the central region of Tanzania:

- Human health, which is threatened by the spread of cholera and other infectious diseases caused by shortages of fresh water

- Power generation, which in Tanzania depends predominantly on hydro-electric plants; in 2006, for example, the country faced severe power rationing because of the shortfall of generated power

The application of the framework to health is relevant for many regions where the life and health of populations is vulnerable to current climate patterns and the potential additional impact of climate change. The application to power generation will be also be relevant in many other regions, and serves as a model for using the framework to assess risks and adaptation responses for specific economic sectors or enterprises. ❍

TEST CASE ON NORTH AND NORTHEAST CHINA – FOCUS ON DROUGHT RISK TO AGRICULTURE

DESERT | CHINA

In February, 2009, drought struck the northern and central regions in China in what the China drought relief office called an event "rarely seen in history". Farmers feared for their crops. In China's major grain-producing base of Heilongjiang province, in remote Northeast (NE) China, soybean seedlings withered under the relentless sun. In North China, 4.4m people and 2.1m cattle lacked adequate drinking water affecting millions of hectares of wheat crops[1]. Good rains from mid-February through March eased the drought, but concern remains that the North and NE of China, making up 23 percent and 24 percent of national economic loss due to drought historically[2], are at risk from persistent drought - concerns that may be exacerbated by possible changes in climate.

This latest event draws attention to the vulnerability to extreme drought of these two important agricultural regions, which are instrumental in feeding China's growing population and in helping the country to achieve food security. By 2030, the two regions will produce 25 percent of China's food crops, underscoring the importance in understanding the impact of drought-related climate change and for undertaking appropriate adaptation measures to protect these vulnerable regions from incurring losses[3].

This appendix summarizes the test case undertaken in North and NE China, highlighting the risk these regions face, the magnitude of the potential loss assessed, the measures that could avert a significant portion of the loss, and the need to overcome potential challenges to implement those measures.

The study drew on an extensive body of existing research. Analyses were conducted in close collaboration with Professor Lin Erda's group from the China Academy of Agriculture Sciences.

LOSS OF $8BN FROM DROUGHT IN RECENT YEARS

Although China is also at risk from flooding and wind impacts, drought constitutes the largest threat to food security in China, with consequent impact on rural social development. This test case focuses on drought impacts on rural and vulnerable society.

To determine where and from what the country is most at risk, we conducted two analyses. We chose drought due to the historical record: since the 1950s, China has been losing increasingly large amounts of vital food crops to drought. Almost every province in China has experienced drought loss at some point over last 50 years. This is taking its toll on the nation's economy, environment and people. China has incurred $8bn in economic losses due to drought in recent years, affecting 21m hectares of crop fields, and leading to the

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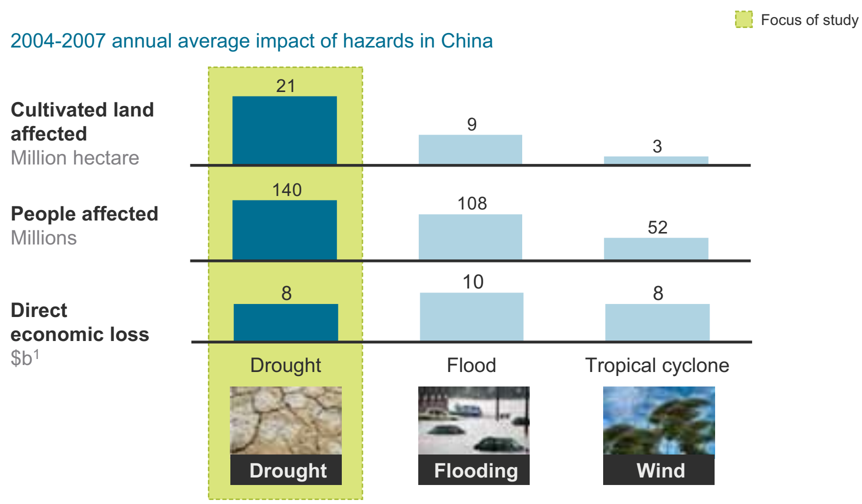
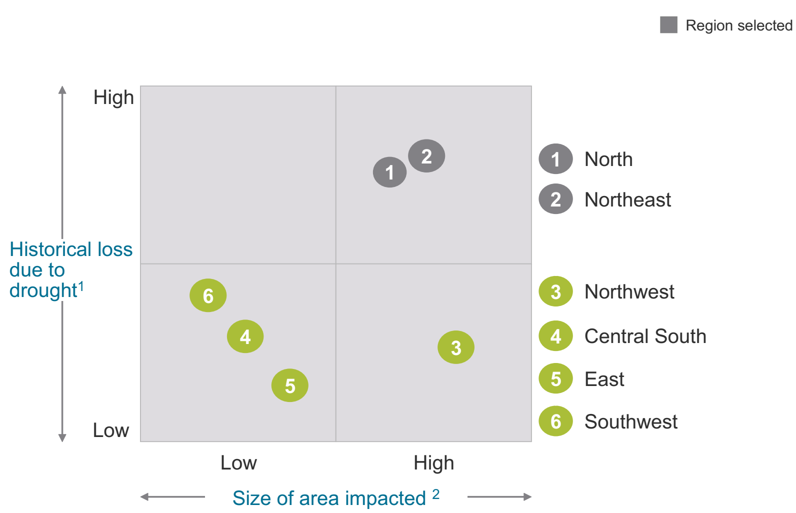
Focus on drought due to its strategic importance to food security and rural social benefits



1 $ 1 = RMB 6.8 for all calculations

02

North and Northeast China most impacted by drought



1 Based on economic loss due to drought during 2004-07
2 Based on the ratio between drought impacted area and drought covered area during 2004-07

suffering of 140m people[4] (Exhibit 1). While drought affects several areas of agricultural importance throughout China, this test case focused on the important crop growing regions of North and NE China – the most vulnerable areas to drought in terms of historical loss and size of crop land affected. (Exhibit 2)

The ratio of the 'drought impacted area' (defined as having >30 percent yield loss) to the 'drought covered area' (defined as having >10 percent yield loss) within a region is a good indicator of those regions having greater vulnerability to drought. This ratio was over 50 percent in the North and NE during 1951-2000[5]. Only North West (NW) China had a higher ratio, but with a much lower proportion of total loss (11 percent of China).

Yield loss from food crops due to drought increased continually from the 1950s to the 1990s, from 7 - 13 percent in North China, and from 2 - 8 percent in NE China[6]. During the 1990s, North China lost a total of 7 million tons in food crops, while NE China lost 5 million tons, accounting for almost 40 percent of national losses. As China's population grows, so does demand for food: China currently produces ~510 million tons of grain annually. By 2030, to meet projected demand from agriculture for food consumption (in line with population growth to 1.4 billion), animal feed and industrial use, that figure will rise to some 590m tons[7] – an estimate based on China's "National Long-Term Plan for Food Security", as well as approved regional goals for food production growth. By 2030, twenty-five percent – equal to the grain production of Brazil – will likely be produced by North and NE China. →

RICE FIELD WORKER | CHINA

In an attempt to stem these losses, China has undertaken a huge effort to fight drought. In the 1990s alone, the government invested $2.4bn in drought fighting measures across North and NE China, with a year-on-year growth of 30 percent.

CLIMATE CHANGE COULD LEAD TO 50 PERCENT INCREASE IN DROUGHT LOSS IN NE CHINA BY 2030

There is considerable value at stake, given that yield and the production of major food crops are expected to increase by 14 percent in total by 2030 in China, from a base of 122 Mn tons of food crop production in 2007 for North and NE China according to the FAOSTAT. The climate change scenarios used for the test case indicate that the expected impact of climate change upon agricultural drought loss in China is likely to vary greatly between regions. We assume the major driving force for production is

Climate change scenarios

03

- PRECIS is a regional circulation model (RCM) developed by It simulates daily meteorological conditions at a resolution of 50 km x 50 km in a selected region of China driven by an emission scenario.
- A2 scenario is an SRES scenario defined by IPCC[1], often referred to as medium-high emission scenario
- Extreme drought in the report refers to particularly severe drought event that happens once every 30 or 50 years

2030 scenarios	Description
1 **Today's Climate**	• Assuming the climate remains the same as historical climate conditions. • Use PRECIS model's output based on 1961-90 data for normal drought • Use historic condition for extreme drought
2 **"Moderate" Change**	• Use the average value of the forecast by PRECIS model under A2 scenario • Assume a 50% increase of the severity and the frequency of extreme drought from historic condition
3 **"High" Change**	• Use the average value of the driest 10% forecast from PRECIS model under A2 scenario • Assume a 100% increase of the severity and the frequency of extreme drought from historic condition

1 The Intergovernmental Panel on Climate Change

demand driven by population growth and the National Framework for Medium-to-Long-term Food Security (2008 – 2020) that sets an objective of 100 percent self-sufficiency for major food crops (wheat, rice, maize, beans and potatoes).

By 2030 climate change could lead to an increase in drought loss in NE China of about 50 percent, while having limited impact on North China. That is not to say the impact to North China can be ignored; even under today's climate conditions tremendous losses are incurred. As the yield base grows and the threat of extreme weather increases, more will be at stake.

In order to understand the potential impact of climate change on drought loss in North and NE China, projections were made under three scenarios: first, the "Today's Climate" scenario, which uses 1961-90 climate conditions; second, a "Moderate Change" scenario, which assumes a medium-high climate risk scenario; and third, a "High Change" scenario, which assumes the driest 10% forecast given the A2 scenario (Exhibit 3).

We chose the PRECIS single regional climate model in consultation with Professor Lin. The PRECIS model is proven to be well calibrated to China, and accepted by researchers in China. While a range of models may better capture the uncertainties of climate change, we wanted to assess the use of RCMs in later test cases as opposed to the multiple GCM methodology utilized in other test cases. RCMs provide the necessary level of granularity to test the hypothesis that climate change will impact different regions of China differently. So, in this case, we evaluated uncertainty and developed scenarios in China based on the range of outcomes given by the single PRECIS model as opposed to assessing the uncertainty displayed by a range of outcomes from multiple models. These scenarios still represent a range of uncertainty that a decision-maker needs to consider.

Under the "Today's Climate" scenario, the expected total loss to both regions by 2030 is $2b. Of that, NE China accounts for $1.1bn (representing a 4.5m ton yield loss, or 4 percent of total production) and North China for $0.9bn (representing 3.1m ton yield loss, or 7 percent of total production).

Under the "Moderate Change" scenario, the total loss rises to more than $2.5b, with NE China losses rising by 50 percent to $1.7bn (almost 7m ton yield loss, or 6 percent of production), compared with a 6 percent rise in the North China losses, to $0.9bn (more than 3m ton yield loss, or almost 8 percent of production). (Exhibit 4)

The reasons for the difference in the impact of climate change upon drought loss in North and NE China are regional differences in climate, crop structure and capability to fight drought as defined by irrigation rate and funding for drought relief. According to the PRECIS model output for A2 scenario (per IPCC definition) or medium-high CO_2 concentration scenario (559 ppm in 2040), climate change may affect precipitation. We developed a drought indicator that assesses precipitation during critical growing seasons based on historical records of seasonal precipitation and drought covered area. Essentially, we correlate past rainfall during the growing season with reported evidence of crop loss. Assessing the data seasonally is important, as illustrated by NE China. Average annual precipitation will increase in the NE, but not in the critical season, according the PRECIS model output, when major crops are particularly vulnerable to drought.

The results of this analysis suggest that climate change leads to a decrease in the critical spring-time precipitation in NE China, putting the rain-fed crops at greater risk of drought. In North China, however, the critical summer-time precipitation is →

Expected losses across the different climate scenarios

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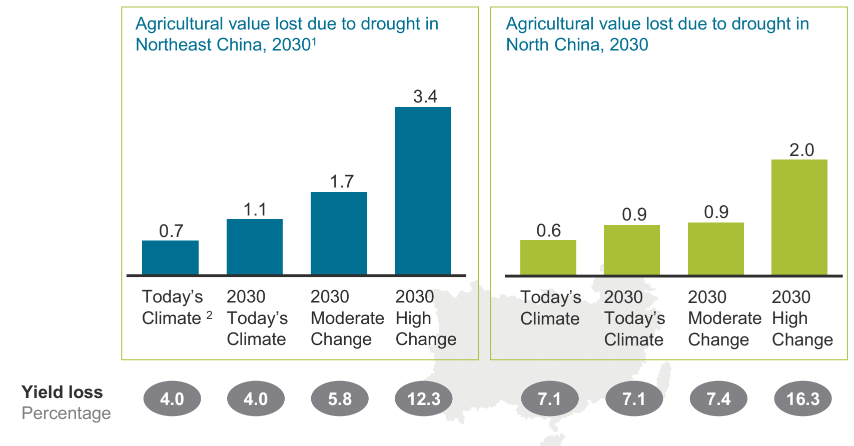
$billion



1 The 2008 GDP in Northeast and North was $ 0.9 trillion and 1.4 trillion respectively; therefore, 2030 drought loss under HC is around 0.1% of 2008 GDP in these two regions. The forecast of 2030 GDP is not included due to high uncertainty

2 Based on 2007 total yield and 1960-90 yield loss percentage for comparison, because the historic climate is based on 1960-90 climate condition

expected to increase slightly reducing the risk of drought when compared to NE China. In addition, NE China's low capability to fight drought, due to lower irrigation rates and less investment leaves it far more vulnerable to severe drought and extreme events – upwards of 35 percent yield loss for extreme precipitation levels with a probability less than 10 percent. (Exhibit 4)

The implication for decision-makers is there is no one-size-fits-all approach to adaptation. Highly region-specific analysis should be undertaken to define the appropriate adaptation strategy and measures.

MEASURES COSTING $15BN HAVE THE POTENTIAL TO AVERT 50 PERCENT OF DROUGHT LOSS BY 2030

An analysis of available drought-mitigation measures must take into account their cost, their suitability in the region and requirements for successful implementation. With this in mind, we analyzed an extensive list of drought-mitigation measures to arrive at four groups of measures, which will be key to reducing drought loss in North and NE China. We started with a list of over 30 measures and assessed them based on applicability to the region, potential to avert drought loss and technical feasibility. Note that we have assumed that all measures must align with the national plan for 100% self-sufficiency in food production. Our work therefore does not consider comparative advantages in crop selection – which may produce a different set of crops for maximum economic benefit. Instead, we have assumed that the present long-term policy will continue in the future. The four groups of measures comprise nine specific measures, which work together to optimize water-resource management along the agriculture value chain. The measures require a total capital investment of $15bn during 2010-2030 in North and NE China.

The first group comprises irrigation measures that include:

- Anti-seepage materials along water-conveyance channel (plastics and concrete).
- Use of plastic and concrete pipes to convey water from source to field.
- Drip irrigation (to drip water slowly to the roots of plants) through a network of valves, pipes, tubing and emitters.
- Sprinkle irrigation to disperse water into the air so that it breaks down into small droplets.

The second group comprises planting measures that include:

- Mulching to place a protective cover over the soil that prevents water evaporation and keeps temperatures consistent.
- Soil-conservation techniques to reduce field tillage and maintain soil moisture.

The third group comprises seed-engineering measures to make plants more drought-tolerant through conventional breeding (not considering genetic modification).

Initial portfolio of cost-effective measures

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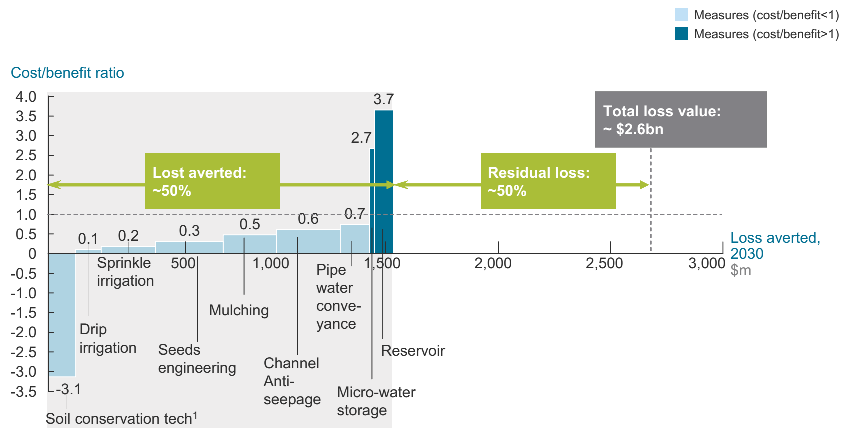
MODERATE CLIMATE CHANGE



1 Negative cost/benefit ratio means there is cost-saving in the long-term. For example, soil conservation technique can save large cost-saving from less tillage operation and fertilizer usage. Its benefit is limited as it has only small loss averted during drought and no yield improvement in normal condition

The fourth group comprises engineering measures that include:

- Building of reservoirs and pond dams to store water for irrigation during seasons of drought.
- Micro-water storage facilities to store water for emergency use in mountainous areas.

These nine measures have the potential to avert 50 percent of drought loss by 2030, with the remaining amount being residual loss. This evaluation of measures to avert economic losses is displayed in a cost curve (Exhibit 5) highlighting the full annual expected loss and the losses the proposed measures can avert. Aside from the engineering measures, all measures have lifetime economic benefits that are greater than their cost.

As in other cases, addressing the climate risk is costly. We estimate a total of some 100 bn RMB cummulative capital investment for North and NE China for the measures assessed between 2010 and 2030, of which some 40 percent will come from individual farmers. Irrigation measures combined comprise 70 percent of the cost and reservoir construction comprises 25 percent of the cost.

Seed engineering could potentially avert some residual loss, though a technology breakthrough would be required beyond the standard hybrid breeding approach evaluated. Further engineering measures may be able to avert a further 1-3 percent of the expected loss: these include water infrastructure measures that would expand irrigation in NE China from 35 percent to 40 percent, and diverting 30 percent of the existing large scale South to North water migration project, which is currently focused on urban and industrial usage, to agricultural irrigation. Other measures such as GMO seeds and crop structure optimization may offer opportunities to reduce the residual loss but we did not evaluate them quantitatively. →

IRRIGATION | GOBI DESERT | CHINA

RICE TERRACES | CHINA

We also identified the value of agricultural insurance to transfer risk in the case of extreme (i.e. infrequent but very severe) droughts. These extreme events carry a risk of higher income loss than in the case of average droughts. Our analysis suggests insurance could cover some 715 mn RMB in the North and some 1 bn RMB in the NE assuming only 30 percent of the loss is claimed, resulting in coverage of around 10 percent of the total drought loss. Agricultural insurance would help to protect farmers against high losses to their income, and make it possible to quickly rebuild their livelihoods in the event of a disaster wiping out crops and livestock; additional risk transfer instruments would reduce the financial burden on the government establish and distribute disaster relief funds. As a result of this, the Chinese government has promoted agricultural insurance strongly in recent years (for example, through subsidization).

While the measures identified have clear potential to avert drought loss in China, the implementation challenges of financial support, capability-building and developing an enabling regulatory environment could prevent them realizing their full potential.

Considerable collaboration will be required between major players and the Government. The key action for government would be to establish an all-encompassing regulatory framework with clear policies and incentives in place to ease implementation. To truly achieve success, the private sector must also play a role, not only in developing goods and services, but also in contributing their know-how and expertise to ensure that strong foundations are built along the entire value chain.❍

TEST CASE ON MAHARASHTRA, INDIA – FOCUS ON DROUGHT RISK TO AGRICULTURE

Maharashtra, a large rural state in the center of India, suffered three years of crippling drought between 2000 and 2004. The ongoing drought caused terrible hardship for the two-thirds of inhabitants who depend on agriculture and allied activities for their livelihoods[8]. As a result of the drought, crops failed, quality of harvests declined, livestock died, available employment decreased, and household debt increased. Many families fell below the poverty line, some starved and several farmer suicides were recorded[9]. Sporadic migrations of families and the movement of people to cities to find temporary employment negatively affected social welfare in the state.

Although Maharashtra has the largest area of drought-prone agricultural land in India, many other parts of India also face the risk of drought from erratic rainfall patterns. This test case therefore serves as a useful initial basis for gauging how the risk of drought might affect agricultural production and across India.

This appendix summarizes the test case undertaken in Maharashtra, highlighting the risk this state faces from drought, the assessed magnitude of the potential loss, measures that could avert much of this loss, and barriers that need to be overcome to implement them.

The test case drew on an extensive body of existing literature as well as on interviews with climate and agricultural scientists and farmers. Analyses by the Indian Institute of Tropical Meteorology provided particularly valuable input to our calculations.

01

Focus on drought due to its large impact on agriculture and human livelihood in Maharashtra, India

Examined further

Hazards	Impact	Comments
Drought/ Heat wave	High	• Deficiency in water supply, typically driven by low precipitation and high temperature • Droughts/elevated temperatures significantly impact agriculture and human lives
Flooding (river or flash)	High	• Hazard posed to regions by fresh water • Floods currently cause significant damage to assets across India
Tropical cyclones	Medium	• Hazard posed by storm surge and wind • Cyclones cause substantial damage to the east coast of India
Sea level rise	Low	• Alteration of coastline driven by sea level rise • Important along parts of India's coast, especially over the longer term
Glacial melt and climate zone shifts	Low	• Hazard from a change in average temperatures and hydrology • While water scarcity may be affected by glacial melt in the indo-gangetic plain, this is likely to be a longer time horizon issue (beyond 2030)

- While all of the hazards identified are important risks to India, the focus of our work was on droughts/heat waves due to it's large impact on agriculture, a key sector for India
- In particular, we focused on the state of Maharashtra – which has the largest drought prone agricultural area[1] in India

1 Based on Drought prone areas program (DPAP)

INCREASED FREQUENCY AND SEVERITY OF DROUGHT

The test case focused on drought and its impact on agriculture, as the hazard that poses the greatest potential threat to India's economic value and livelihoods over the next 20 years. While Indian agriculture already faces considerable historical drought risk, climate change could worsen this risk significantly, both by increasing temperatures and reducing rainfall.

Climate change poses several other risks to India, including increasing the severity of tropical cyclones, which cause damage along the east coast, and of flooding, which already causes widespread flooding across India. Sea-level rise and glacial melt (in the Indo-Gangetic plain) are further potential impacts of climate change, although these are projected to be felt over a longer period than the 2030 timeframe used in this study[10]. Exhibit 1 illustrates the range of hazards identified during the test case and supporting rationale for focusing on droughts.

Maharashtra makes up 26 percent of the overall drought-prone agricultural area in India[11]; 23[12] of its 35 districts receive less than 1m of rainfall per annum[13]. "Today's climate" thus already puts Maharashtra at significant risk from drought. →

Climate change scenarios

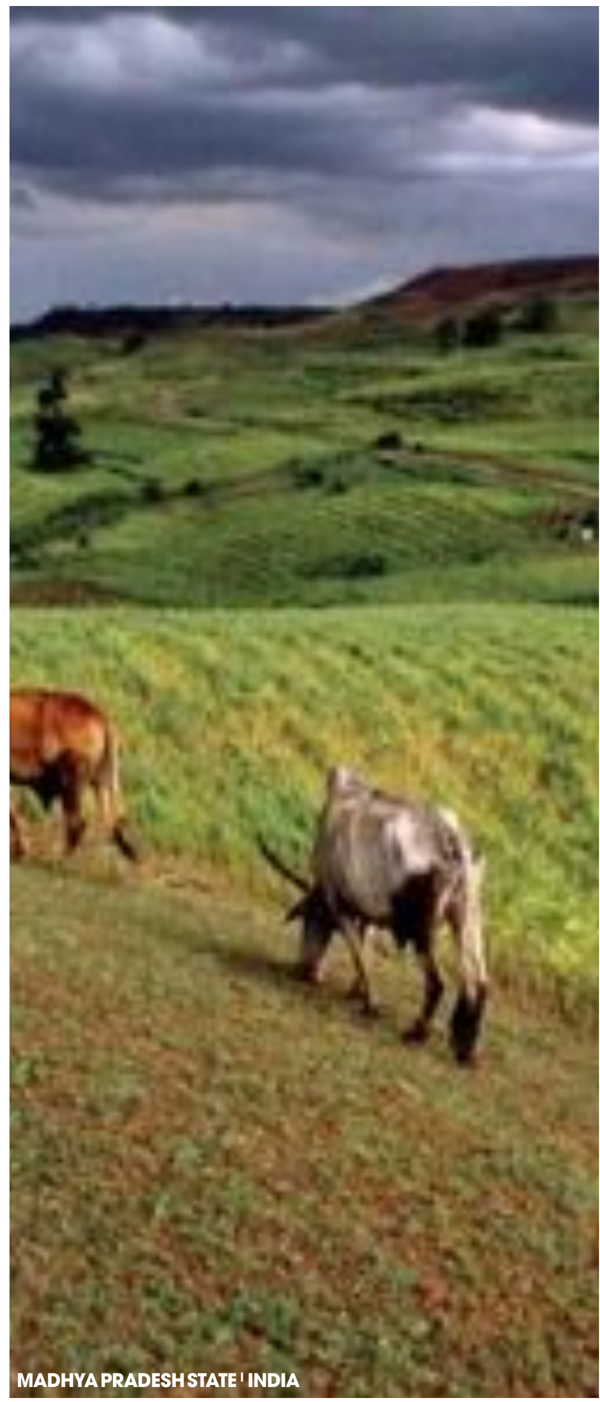
02

- Predicting local climate is inexact given limited data. Therefore, 3 scenarios were developed for rainfall change in the 2030 timeframe
  - Based on temp and precipitation predictions from 22 global climate models
  - Distribution in rainfall varied from 92-102% of today's value
- While some regional climate models exist assessing at a higher resolution and smaller grid area than GCMs, the science behind these models is still developing
- Climate scenarios were later used to develop 3 hazard scenarios

2030 scenarios	Description
1 **Today's climate**	• **Historic rainfall and drought data used** to estimate rainfall frequency
2 **"Moderate" change**	• Average change based on the **mean rainfall predicted** from 22 GCMs[1]
3 **"High" change**	• Extreme change based on **average of 90th percentile values** for predicted rainfall from 22 GCMs

GCM results consistent with output from **regional models** (A2 and B2) for Maharashtra

1 22 GCMs for Maharashtra, run with the A1B scenario



MADHYA PRADESH STATE | INDIA

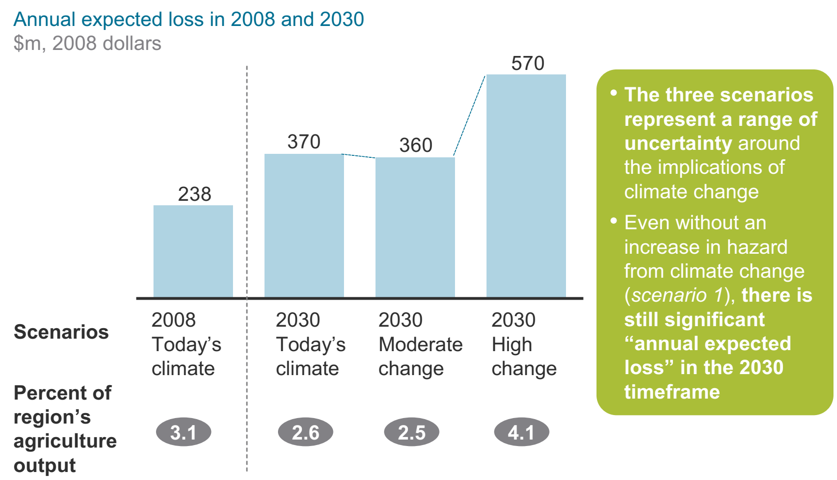
The climate change scenarios for the test case, drawing on modeling from Professor Reto Knutti[14], found that this risk could be exacerbated significantly, even in the next two decades. By 2030, a scenario of "High Change" could result in an 8 percent decrease in annual rainfall across the state. This could result in a several-fold increase in the frequency and severity of droughts. It is possible that droughts that currently occur once every 10 years could be occurring as frequently as every 3 years by 2030. As in other test cases, we use the climate scenarios to adjust the profile of precipitation. In India, over 100 years of historical precipitation and temperature record exists, allowing us to construct a loss exceedance curve as described in the Methodology Appendix. In this test case, we used climate scenarios to shift the hazard profile –percentage reduction in rainfall by frequency of occurrence – according to the average change in precipitation. Exhibit 2 outlines the three climate scenarios developed to reflect the uncertainty in future climate. The average of the 22 GCMs for the IPCC A1B scenario shows a slight increase in average precipitation whereas the 90th percentile of the GCM range of results indicates a possible decrease in precipitation.

POTENTIAL ANNUAL LOSS OF OVER $500M

The study put together a detailed picture of the region's agricultural economy today; of the most likely development to 2030 in the light of development plans for Maharashtra and India overall economic trajectory; and, of the losses that could be caused by

03

Expected losses across the different climate scenarios



the climate risks identified. In 2008, agriculture in the drought prone area in Maharashtra generated economic output of approximately $7.7bn[15]. The current figure for expected annual loss from drought stands at almost $240m in 2008 – equivalent to some 2.5 percent of the state's agricultural output. The greatest asset value at risk today is sugarcane. However, the most valuable crops (sugarcane and horticultural crops) are also primarily grown in irrigated areas, and are therefore the most resilient to climate. We estimate the growth of the agricultural asset value to double by 2030, driven by a shift towards higher value, horticultural crops and sugar cane, as well as population demand growth. Interviews with local farmers support the expected shift to horticultural crops. Achieving the agricultural growth will require completion of currently planned irrigation and crop efficiency projects. We assume these measures in the baseline growth in asset value.

We assessed vulnerability to drought for each crop. For jowar, bajra, wheat, rice, groundnut, turn, gram and sugarcane we used analysis on 30 years of production and rainfall data to determine yield and crop area vulnerability. We used analogous crops for those where data was not available.

Applying the probabilistic loss model combining the hazard profile of losses, climate scenarios, asset value and crop vulnerability, our study calculates that by 2030, the moderate climate change scenario could increase drought-related losses to agricultural value by 10 percent compared to the current climate risk, while high climate change could increase this by as much as 50 percent above 2008 losses. This figure is slightly below 3 percent of the 2030 anticipated production for the area, reflecting the extent to which some adaptation measures (notably planned irrigation infrastructure projects) are being put in place in Maharashtra.

In the "high" scenario, climate change would increase the risk of drought and exacerbate losses amongst all crops. Overall, the study showed that the high climate change scenario would lead to an expected annual loss in 2030 of $570m – compared to $370m under the "today's climate" scenario. Exhibit 3 outlines the summarized results of expected annual losses across the different climate change scenarios.

While the focus in the test case was primarily on economic value and average expected loss, we also estimated the number of human lives impacted by drought, as well as the impact on subsistence farmers, which is likely be proportionately much greater than the losses to overall GDP. For example, a specific extreme event (a 1-in-25 year drought) may affect up to 30 million people, or 30 percent of Maharashtra's population – including 15 million small and marginal farmers. The same event would reduce 14 percent of agricultural output and 30 percent of food grain production. The impact is particularly severe for small farmers (with an average annual household income of $546) and marginal farmers ($440). Without any drought, these individuals face an annual deficit because their consumption is greater than what they produce. A 1-in-25 year drought increases their debt by 26 percent and 96 percent, respectively. In addition to humanitarian concerns, these small and marginal farmers are important because they represent 41 percent of cultivated land by area and 68 percent of the number of farming households. →

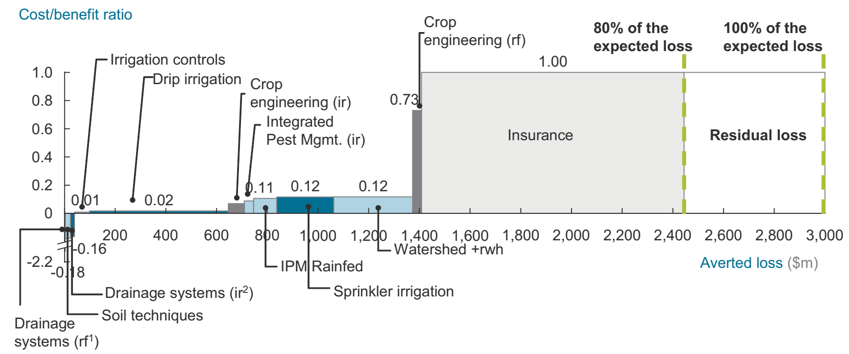
A COST-EFFECTIVE PORTFOLIO OF CLIMATE RESILIENCE MEASURES COULD REDUCE LOSSES BY 80 PERCENT

What, then, can decision-makers in Maharashtra – and in other locations in India faced with comparable climate risk – do to address the risk and shape climate-resilient development and regeneration paths? Comparing their costs and benefits, a range of measures was evaluated, including infrastructural measures, such as drip irrigation and sprinkler irrigation; engineering measures, such as crop engineering; behavioral measures such as watershed management and soil techniques, and risk transfer measures, including crop and weather index insurance. After listing an exhaustive set of alternatives in these four categories of over 30 measures and filtering out those that are not applicable to Indian agriculture or not feasible or recommended by local experts, we conducted a cost-benefit analysis. Some of these measures, including last-mile irrigation, rehabilitation of irrigation systems, ground water pumping, planned irrigation products, and canal lining are planned government projects that are already "factored into" the baseline loss assessment, and so are not considered as additional measures to protect against drought risk.

Our cost-benefit exercise of the final short list of measures, represented in Exhibit 4, found that Maharashtra can avert the bulk of its expected drought loss to 2030 through measures whose economic benefits exceed or approximate their costs.

04 The initial portfolio of responses cost-effectively averts much of the expected losses

Risk transfer
Systemic/behavioral
Technological/procedural optimization
Infrastructure/asset-based



- A large share (~50%) of measures have lifetime economic benefits greater than costs (NPV>0)
- Micro irrigation measures (drip, sprinkler irrigation), watershed management and insurance are key measures (addressing 70% of the expected loss)

1 Rf = rain fed agriculture
2 Ir = irrigation fed agriculture

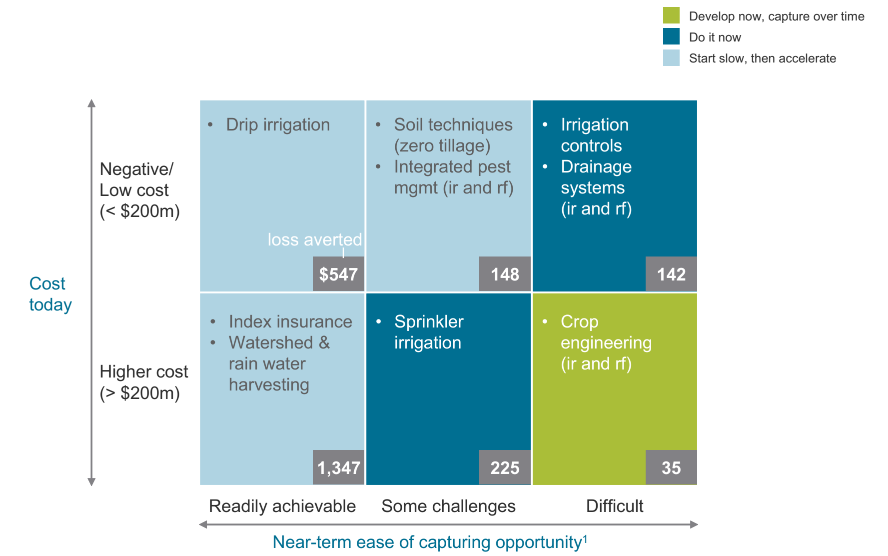
As expected, measures that improve yield – and therefore create economic benefit as well as operating cost savings that reduce labor or other input costs – perform best in the analysis. For example, drainage systems in rainfed settings, soil techniques, and drainage systems in irrigated settings all have negative cost-benefit ratios. Drip irrigation has the highest absolute level of loss averted with $547 mn. It is the capital cost of drip irrigation that leads to the positive cost-benefit ratio result. In total, the 12 measures evaluated have a capital cost of $6.7 bn.

For events of a very low frequency, insurance measures – to transfer rather than directly prevent the expected loss – may prove a cost-effective component of the portfolio. These measures include increasing the penetration of crop and index insurance. The insurance measure on the cost curve is illustrative, given the assumption that risk transfer benefits calculated from the expected loss model are equal to the societal costs. The actual cost-benefit ratio of specific insurance measures depends on the type of insurance and transactional costs. In terms of specific insurance options, our analysis suggests weather based index insurance is the most attractive. Weather based index insurance options cover the economic loss of crops based on weather indices. Its benefit is that it covers up to 70 percent of the economic value lost, and pays out within 30 days of the event

The evaluation of measures shows that there is still some residual loss: the full annual expected loss cannot be averted through the measures identified, with the implication that relief and rehabilitation responses will need to be included in the package of responses adopted. The reason for this residual loss is that, even if all the identified measures were implemented to their fullest extent, there will still be rare, high-severity drought events that cannot be addressed by these measures alone.

Decision-makers tasked with assembling a portfolio of measures to strengthen climate resilience must also consider factors other than costs, such as barriers to the implementation of various measures. Consideration of these led to the identification of

05 Five cost-effective measures for near-term implementation



1 Based on financing issues, regulatory support, agency issues, entrenched behavior, supply constraints and technological readiness

five key measures that can be implemented in the near term (Exhibit 5), including drip irrigation, soil techniques, integrated pest management, insurance, and watershed/ rainwater harvesting.

There are several actions that can be taken to overcome barriers to implementation. For example, additional government funding of micro-irrigation schemes (drip and sprinkler irrigation) can increase the penetration of these schemes and achieve scale. Also, NGOs have a critical role to play in unlocking the potential of watershed/ rainwater harvesting, they are currently severely capacity constrained. Increased government funding to NGOs would increase their capacity and enable them to train greater numbers of rural residents to implement these measures.

The government currently subsidizes traditional crop insurance programs, but penetration is currently very low. Index insurance – which quickly pays out farmers based on indexed measures such as rainfall below a certain level, rather than on individual loss claims – could be a key risk transfer scheme going forward, and government could partner with private providers to encourage its adoption. Index insurance schemes will also require the creation of additional weather monitoring systems, to reach at least one weather station per district.

Drought has the potential to cause significant economic and human damage in Maharashtra, and across much of India – and climate change could worsen this damage significantly, even within the next 20 years. Although the implementation challenges will be considerable, decision-makers have the opportunity to put together an effective portfolio of climate resilience measures, at limited cost. ➔


THAR DESERT | INDIA

CATTLE ON WET PLAINS | MALI

TEST CASE ON MOPTI REGION, MALI – FOCUS ON RISK TO AGRICULTURE FROM CLIMATE ZONE SHIFT

Mali is situated in the north western part of Africa stretching deep into the Sahara. The country is dry and semi-arid and subject to frequent droughts. Increasing temperatures and decreasing rainfall tell the story of the shift in climate zones as the Sahara desert encroaches southward over productive land. In the affected regions, farmers dependent on agriculture and livestock for subsistence find it very difficult during drought periods and have few options to overcome the hazard. Many of them are moving to the cities, while others are moving to the less arid south of the country. Those who stay are increasingly asking NGOs for help in adapting to these harsh climatic conditions. Some have begun to complement household income from parallel activities such as handicrafts.

This appendix summarizes the test case undertaken in Mali, highlighting the risks the country faces, the magnitude of the potential loss assessed in the agricultural sector, and the measures that could avert that loss and promote climate-resilient development. The study focused on Mopti, an important agricultural region in central Mali. The study drew on an extensive body of existing research and local knowledge. Data of the Ministère de l'Agriculture, Direction Régionale de l'Agriculture et l'Élevage de Mopti and the Service National de la Météorologie, as well as local NGOs and in particular the Near East Foundation were particularly important for our assessments. Climate data provided by the Stockholm Environment Institute (SEI) and IPCC were essential for our modeling as well. Additionally, a specific analysis of the vulnerability of agricultural and livestock yields to climate scenarios was developed in collaboration with the International Food Policy Research Institute (IFPRI) for agriculture, and the International Livestock Research Institute (ILRI) for livestock.

RISK FROM CLIMATE ZONE SHIFT – A COUNTRY THAT HAS BECOME HOTTER AND DRIER

Mali has a wide variety of natural environments, ranging from a Saharan climate in the north (less than 200 mm of annual rainfall), to the more-tropical climate in the south (>1200 mm/year)[16]. Population density follows this variation in climate, with most of the people living in the southern regions or within the Niger Delta. Additionally, Mali has to cope with some of the highest rainfall variability on earth: the annual shifts in precipitation can go up to 200-300 mm of rain, or almost 100 percent change.

In the context of these climate difficulties, Mali also faces various hazards from climate change. Drought is expected to increase in frequency and in severity, negatively affecting agriculture and GDP. Flooding occurs each year during the rainy season in the interior delta of the Niger River. While benefiting agriculture, flooding is potentially harmful to the local population, particularly as the increase in population and the lower flooding levels of recent years have seen homes being built on lower ground, but the uncertainty in climate projections on future rainfall trends in Mali makes it difficult to predict how climate change will impact on flooding. Mali is also experiencing climate zone shift (a change in average climatic conditions consisting of rising average temperatures and declining average rainfall) with a shift of agro-ecological zones to the south, evidenced by the historical decrease in average rainfall of about 200 mm over the past 50 years and an average increased in temperature of 0.5°C.

01

Focus on climate zone shift due to its large impact on human livelihood and growing concern

Hazards	Impact	Comments
Flooding (river)	Low/High impact	• While flooding can be significant, it may have less human impact and food security concerns compared to other hazards
Drought	High impact	• Agriculture is core to the economy and to the subsistence of a majority of the population • Climate variability is a key aspect of agriculture vulnerability • Drought can affect large areas of Mali and a large share of the population
Climate zone shift - increased desertification of land (Examined further)	High impact	• Climate zone shift is already a major concern in the Sahelian region, with a significant downward trend in the past 50 years (-200 mm rainfall) • A further decrease in rainfall due to climate change would increase this shift • Increased zone shift will require a significant change in agriculture practices for the entire country, and potentially lead to further migration • Food security issues from the increased migration will acerbate and require government involvement

Low impact
High impact
Examined further

- While flooding and drought are important risks to Mali, the focus of our work was on climate zone shift
- Increased migration from the zone shift may constrain resources and health services as the population density increases in the Niger River basin

Mali is experiencing climate zone shift (a change in average climatic conditions consisting of rising average temperatures and declining average rainfall) with a shift of agro-ecological zones to the south, evidenced by the historical decrease in average rainfall of about 200mm over the past 50 years and an average increased in temperature of 0.5°C

It is worth noting that the variability in impacts of climate change on desertification and climate zone shift are aggravated by agricultural and domestic practices that enhance soil erosion, such as slash and burn agriculture, deforestation to meet about 90 percent of Mali's cooking and heating requirements. Forest cover has decreased by almost 50 percent since the 1980s.

Yet, it is important to recognize that farmers have developed techniques to help them cope with this high variability. A significant share of the loss due to climate change could be avoided through such local adaptation. For example:

- ☐ Diversity in crop cycles is key to adapt to climate change – both late and early-maturing ecotypes are encountered
- ☐ Genetic diversity appears to remain an important factor in the resilience of the cropping systems in areas with higher climatic risks
- ☐ Additionally, farmers also tend to spread out geographically, leveraging different types of soils and water sources

The Mali case-study focused on analyzing the potential impact of climate zone shift on agriculture and the keeping of livestock, since this is uniquely different from an event-driven hazard and expanded the methodology to consider impacts from averages shifts in temperature and precipitation (Exhibit 1). ➔

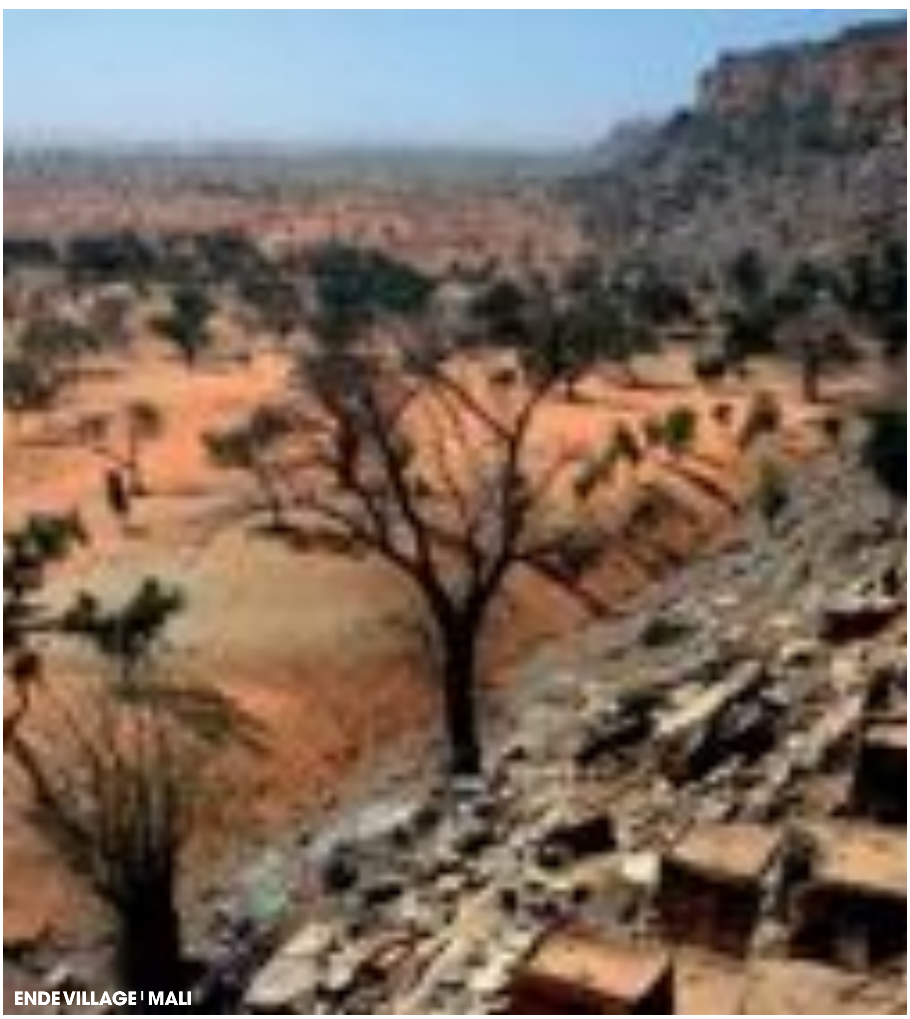
Climate change scenarios

02

- Predicting local climate change is inexact given limited data. Therefore, 3 scenarios were developed based on temperature and precipitation predictions from 22 global climate models
- While some regional climate models exist assessing at a higher resolution and smaller grid area than GCM, the science behind these models is still developing for Mali

2030 scenarios	Description
1 **"Moderate" change**	• Projections based on the **median estimate** of the 22 GCMs – Temperature increase: 1.2°C – Precipitation decrease: -2.2% • Results in **lower agriculture yields** and **lower biomass production**
2 **"High" change – positive**	• Projections based on the **5th and 95th percentile** of the 22 GCMs – Lowest temperature increase (5th perc.): +0.9°C – Highest rainfall increase (95th perc.): +8.1% • Results in **lower agriculture yields** and **higher biomass production**
3 **"High" change – negative**	• Projections based on the **5th and 95th percentile** of the 22 GCMs – Highest T increase (5th percentile): +1.4°C – Highest rainfall decrease (95th perc.): -10.6% • Results in **lower agriculture yields** and **lower biomass production**

1 Extractions from 22 General Circulation Models (GCM) for area around Mali, by Prof. Reto Knutti, ETH, Zurich


ENDE VILLAGE | MALI

POTENTIAL ANNUAL LOSS OF UP TO $300M

Climate conditions are already challenging in the Sahelian region. Without adequate adaptation, climate zone shift will decrease the yields of agriculture and livestock, impacting the livelihood of a large share of Malians and likely accelerating the current migrations towards the south of the country, which are driven by low yields and shrinking water resources. Historically, however, communities in Mali have been accustomed to farming in conditions of wide variability in rainfall; this makes estimating climate-related loss more uncertain, as the potential exists for autonomous adaptation.

THE VALUE OF MALIAN AGRICULTURE

Estimates of the economic output of crops and livestock in Mali were based on the latest statistics of the Ministry of Agriculture[17]. Crops are estimated at $840m for 2006, and livestock at $620m. Projections to 2030 take into account the most valuable agricultural crops (maize, millet, sorghum, rice and cotton) and livestock (for meat, milk and eggs). Projections of the cultivated surface area are informed by an increase of the population. Following historical expectations, the value of those five main crops would increase 46 percent from the current $836m to $1,221m (1.6 percent annual growth). In a more optimistic growth scenario, the value would more than double to $2,474m by 2030 (4.6 percent annual growth). This growth reflects the emphasis on increasing yields for Mali's economic development.

Livestock income is expected to increase by about 40 percent by 2030 driven by growth in population and GDP per capita.

CLIMATE ZONE SHIFT SCENARIOS

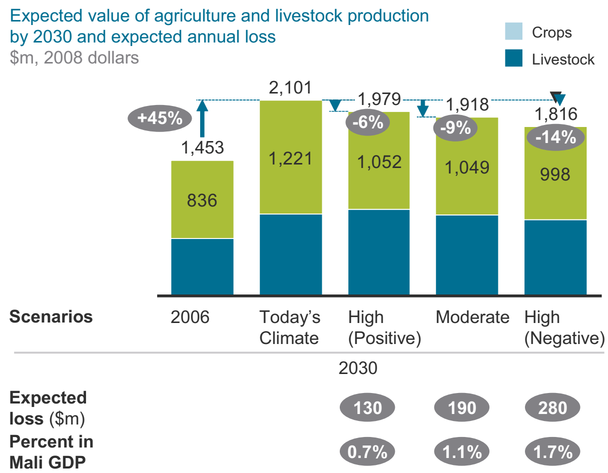
The significant uncertainty in climate change, particularly in the Sahel, leads to a range in climate projections, particularly in respect of rainfall. Three scenarios of climate zone shift by 2030 were considered[18]: A moderate change scenario reflects the average of all 22 Global Climate Models (GCMs) with an average increased temperature of 1.2°C and a decrease in annual rainfall of 2.2 percent. A high change positive scenario projects an increase in rainfall by 8.1 percent with a low temperature increase of 0.9°C. A high change negative scenario projects a decrease in rainfall by a significant 10.6 percent and temperature increases by 1.4°C. Exhibit 2 summarizes the scenarios developed during the test case. The scenario structure is different from an event based hazard.

VULNERABILITY OF YIELDS TO CLIMATE ZONE SHIFT

Assessing climate zone shift requires some adjustment to the framework as presented in the Methodology Appendix. In the case of event driven hazards (like drought), a probabilistic approach is used. But in the case of a shift in climate zone, vulnerability is assessed based on the impact of gradual change on average conditions. To model anticipated yields under shifting climate zones, we assessed economic loss through scientific simulations of crop and livestock developments. These models leverage local

03

Expected losses across the different climate scenarios



- **The 3 scenarios represent a range of uncertainty** around the implications of climate change and the expected growth in Mali
- **Loss due to asset growth** is of
  - **30% for livestock**
  - **33% for agriculture**

conditions to estimate the yields of crops and biomass (temperature, precipitations, soil types, etc.). We collaborated with widely recognized international research institutes, IFPRI and ILRI, to estimate the potential increase/decrease in yield based on the three projected climate change scenarios.

RESULTING ECONOMIC LOSS

Under all three climate scenarios Mali would suffer from economic loss by 2030 due to climate zone shift. A pessimistic climate scenario with sharp reduction in rainfall (-11 percent) coupled with an increase in temperature (+1.4°C) could lead to a potential loss in value of about $300m annually (about 15 percent of agriculture and livestock value). On the other extreme, an optimistic scenario where increases in precipitation (+8 percent) as well as in temperatures (+0.9°C) would lead to a loss of only $120m annually, or 6 percent of value. Interestingly, even assuming no increase in yields, about 30 percent of the value lost is due to the increased value of assets driven by assumptions on population and economic growth. Exhibit 3 summarizes the resulting economic loss expected under the various climate change scenarios.

The study assessed a range of measures to protect Mali's agriculture against these losses, and to promote climate-resilient agricultural growth.

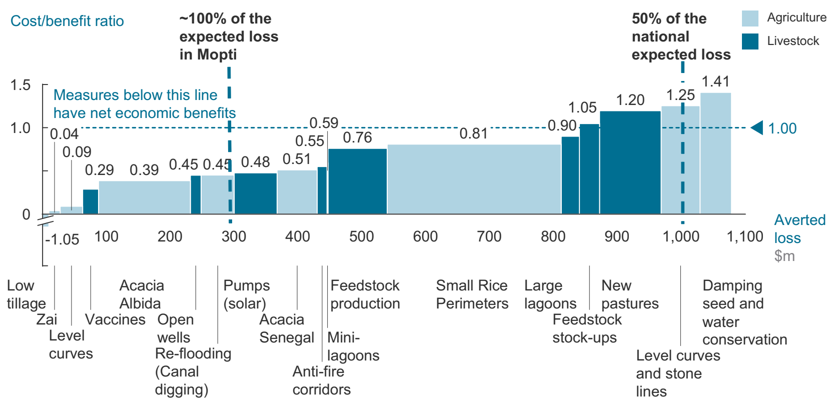
Without any specific adaptation measures, Mali is likely to increase the value of its agriculture by encouraging development in the regions best suited to farming and by promoting the right crop mixes. The human migrations required to shift to these regions are likely to happen naturally. Still, they would not cover the full expected climate-related economic loss, and the measures identified in this study look to address this remaining loss. Technical measures can be applied to compensate for the effects of climate change or generate additional revenues.

Measures to increase productivity by encouraging asset development only in the most promising areas (often related to asset and people migration) can compensate for →

Many attractive measures exist to avert losses on existing land and livestock in Mopti

04

HIGH (NEGATIVE) CHANGE SCENARIO



- Many different measures exist to avert the loss for **both agriculture (66%) and livestock (33% of potential)**
- About **80% of them offer attractive benefits**, with low tillage even at negative cost
- Altogether they avert more than **$ 1 billion, much more than the expected loss in Mopti**

losses in other areas. Simulations showed that by 2030 a migration of 1m people could achieve 6 percent more agricultural production than in the case of even population growth across regions. An accelerated rate of migration, leading to 1.5m migrants by 2030, could provide an additional 8 percent of production (overall 14 percent increase compared to the base case). But such measures are controversial for various reasons. They could lead to conflict and increased competition for resources such as land. They would also require politically sensitive, large-scale infrastructure spending in the south (for example, Delta area) with incentives to encourage migration. However, infrastructure and asset based measures are available to improve resilience in semi-arid areas, so this adaptation approach is not necessary.

Infrastructure and asset based adaptation measures can be highly beneficial in improving climate resilience. Because these depend on the specifics of each natural environment, we assessed a few most promising measures for the region of Mopti, which, situated in the middle of the country, well represents Mali's diverse agro-ecological zones. The south west, by the Niger River's internal delta, is suitable for rice cultivation, horticulture, fishing and livestock. The east and north of the region, with a hotter and drier climate typical of the Sahel, is more suitable for dry crops like millet and sorghum and is threatened by the advance of the desert and the struggle to find water.

Some asset-based adaptation measures (such as soil techniques, irrigation systems and the provision of additional water for cattle) would help to "climate-proof" yields and avoid loss from climate change. We identified measures that would reverse yield loss cost-effectively. About three quarters of the potential of these measures provide higher benefits than costs. Other measures would be able to generate additional agricultural revenues, such as by extending the land area for horticulture, obtaining two harvests per year rather than one, or from additional products (such as mixing agro-forestry in crop fields). It is important to note that the new revenue generation is essentially another adaptation alternative and while it has massive potential, it requires careful consideration of the secondary effects it would have on the society. For the region of Mopti alone, revenue generating cash crops could cover a large portion – if not all – of the expected loss for the entire country. In other words, these types of measure are essentially economic development actions.Exhibits 4 and 5 identify the proportion of measures having a cost/benefit ratio of less than 1, showing that for the small Mopti region cost-effective measures exist to avert all of the loss in terms of annual expected loss. Exhibit 4 assesses the measures without considering the revenue benefits of cash crops and focuses on existing land and livestock. Exhibit 5 expands the analysis to show how the prioritization would change if cash crops and new land were considered.

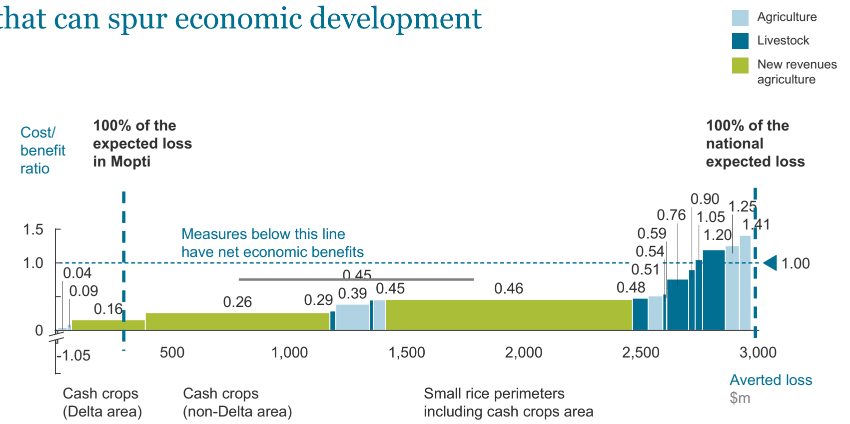
ENABLERS AND BARRIERS FOR IMPLEMENTATION

Many of the measures identified are quite labor-intensive. Hence the availability and use of local labor can constrain both the potential and speed of deployment. Labor is also an additional economic cost to consider, but measures are often financed by NGOs in exchange for free labor as the farmer's contribution to the measures. Machinery often results in better cost-benefit ratios (for example anti-fire corridors). The choice between promoting the local workforce must be weighed up with the benefits of using more efficient and expensive machines. For example, building local water holes (for livestock to drink close by villages during the dry season) can take up to 2 months for a team to build, while a bulldozer will dig it in a day. However, the workforce is usually idle during the dry season, suggesting the complexity in weighing choices. ➔

05

Attractive measures exist for new land that can spur economic development

HIGH (NEGATIVE) CHANGE SCENARIO



- Developing new areas for cash crops has massive potential, with an additional $ ~2 Billion
- This potential has net economic benefits, as it significantly improves the productivity of rice perimeters
- These measures are closely related to economic development

CATTLE HERD | MALI

Many of the measures described above are cost-effective and make sense from a purely developmental perspective. They are no-regret moves in the face of the uncertainties of climate change and could best be channeled through actors typically involved in development: local, national and regional governments, international funds, NGOs, research institutes and the communities themselves. The sooner they can be applied at large scale, the more they will contribute to Mali's climate resilience and general development.

However, based on local interviews it is apparent that development schemes have not always been very successful in the past and lessons can be learnt from them to make adaptation more effective in Mali. Faster and wider implementation of solutions require removing of bottlenecks and creating the right environment through policies, institutions, infrastructure and access to finance, leveraging the full spectrum of public sector interventions available to governments. Support is needed along the entire agricultural value chain: technological developments must meet the needs of farmers and make agricultural advances accessible; farmers need to be adequately trained, incentivized and mobilized to implement solutions that increase their productivity; and market access must be ensured to motivate surplus generation and the implementation of value added activities beyond subsistence. Finally, policy and institutional barriers are also important drivers for implementation for example in clarifying land property rights.

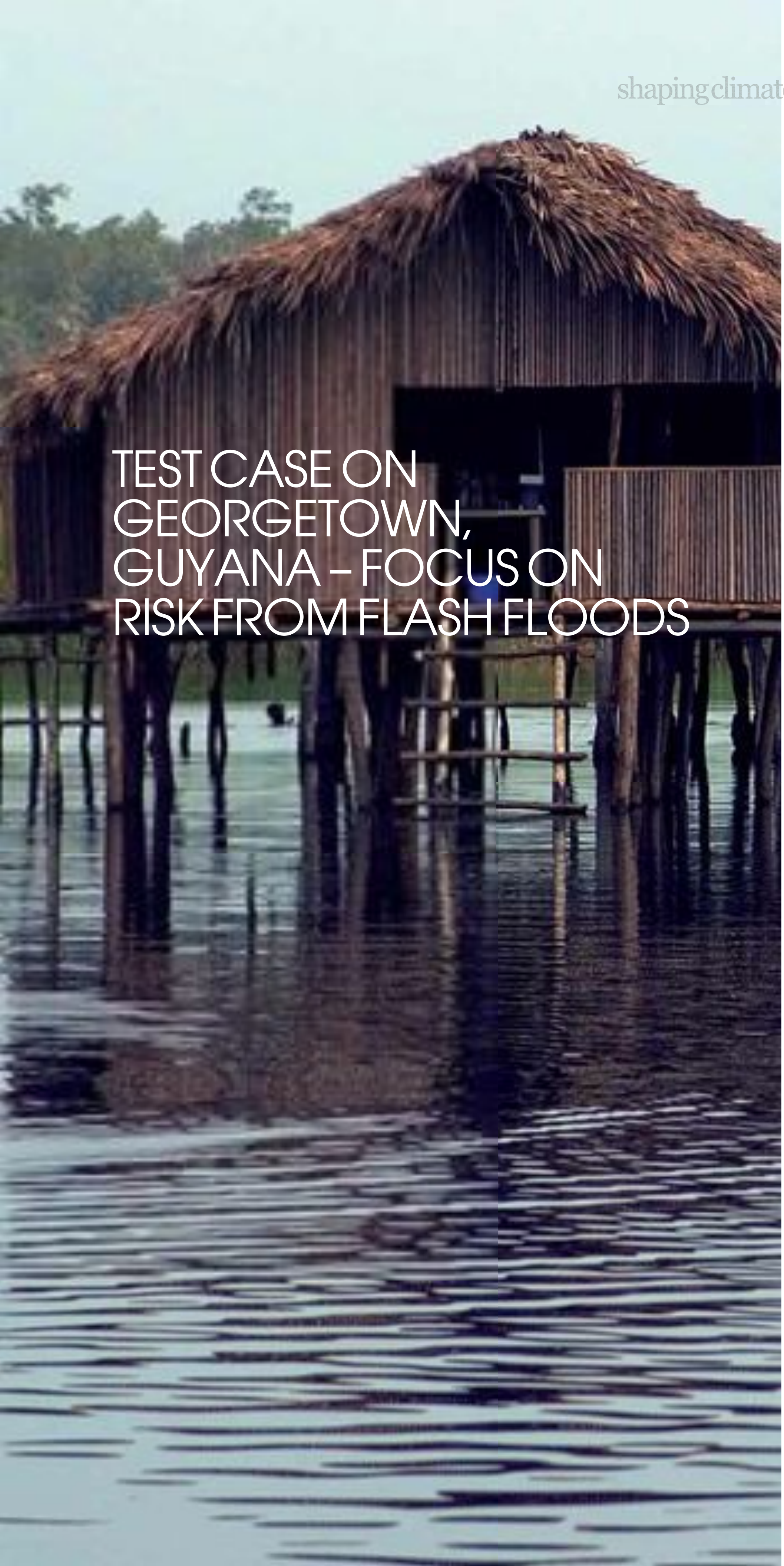
The implementation of adaptation solutions will be led, financed and scaled up by different actors depending on the nature of the measures:

- Government will be required for larger-scale infrastructure measures, such as irrigation in the Delta;
- Smaller-scale measures watershed measures are best encouraged by NGOs in their local environment;
- International institutes can provide important expertise on issues such as crop engineering and meteorological information.

Given the complexity and magnitude of the challenges of adaptation, from conception to implementation, adequate support from the international community will be critical for success. This support should take into account the differences in scale, actors and type of interventions required.

Mali is already highly vulnerable from variability of its current climate and its low level of economic development. Climate change could significantly aggravate this situation by putting additional pressure on livelihoods and revenue streams and leave the population increasingly exposed to risk. Decision-makers have the opportunity to put together an effective portfolio of climate resilience measures at limited cost. The key, though, will be to create the right enabling environment to allow for effective adaptation – and by the same token, for economic development.

Given the relatively early stage of Mali's development, there is much room for improvements in agriculture and livestock. There is consequently a wide range of adaptation options which often overlap with developmental measures, making them worthwhile actions regardless of uncertainties in climate change projections. ❍



TEST CASE ON GEORGETOWN, GUYANA – FOCUS ON RISK FROM FLASH FLOODS

The flood that struck Guyana in 2005 caused such unprecedented damage to assets and livelihoods that local people dubbed it the "great flood". Yet Guyana's geography has made it prone to flooding throughout its history. A narrow plain along its Atlantic coast provides fertile agricultural land and supports 90 percent of the country's population, including that of Georgetown, the capital and largest city. Yet much of this land lies below sea level and cannot easily drain after the rainstorms that are characteristic of the region, putting Guyana at high risk of flash floods[19].

This appendix summarizes the pilot test case undertaken in Guyana, which focused on Georgetown as the location in which the greatest population and economic value is at risk. The study gauged Georgetown's total climate risk, assessed the magnitude of the potential loss from this risk, and evaluated the measures that could avert that loss and promote climate-resilient development.

Because of Guyana's high levels of poverty and lack of suitable flood-protection infrastructure in the face of flood risk, this study formed an urgent test of the methodology described in the report. The country is already the recipient of funds from the EU and GEF allocated specifically for adaptation purposes due to its high vulnerability to climate change.

The study drew on an extensive body of existing research, relied on numerous and broad-ranging interviews with external experts, government ministries, private-sector players, and multilateral and local NGOs.

Focus on rain-induced flooding due to its large current impact on population and economic activity

01

Low impact
High impact
Examined further

Hazards	Impact	Comments
Flooding (rain)		• Flooding has historically been a key risk because of severe rains, large low-gradient river system, and slow drainage • The coastal plain is expected to continue to be susceptible to floods
Coastal flooding (sea level rise)		• Sea level rise is expected to be a critical issue over the long term, but coastal risk is not envisaged to be significant by 2030 • Specific storm surge events are not expected to be a major issue as Guyana's equatorial location precludes hurricanes
Drought		• Drought events may be exacerbated by changing precipitation patterns. However: – Agriculture is concentrated along the coastal strip where it is mostly irrigated – Drought risk primarily occurs inland
Wind damage		• Historically, wind damage is not an issue as Guyana lies too close to the equator for high winds and tropical hurricanes

RAIN-RELATED FLOODING IS THE PRIMARY CLIMATE HAZARD

We assessed a range of relevant hazards for Georgetown, including flooding driven by rain, coastal flooding due both to tidal sea inundation and the increasing risk of sea level rise, drought and wind damage. (Exhibit 1)

Rain-driven flooding is historically a key risk: Georgetown has experienced five major rain-related flooding events since 1990[20]. This flooding is the result of a combination of factors, including the large low-gradient river system that bounds Georgetown, the slow drainage of the coastal plain, and the location of much of the city's urban development below sea level. These factors necessitate engineering measures, such as drainage canals. Maintaining sea wall protection that has developed over the course of centuries is already a critical concern, given the possible impacts of sea level rise – however these impacts are projected to occur over the next 100 years, a longer period than the study's 2030 timeframe.

The other climate hazards assessed are not expected to create major risk for Georgetown and Guyana over the coming decades. Storm surge events are not a major concern as Guyana's equatorial location precludes hurricanes. Drought events in the country's interior may be exacerbated by changing rainfall patterns, but agriculture is concentrated along the coastal strip, which is largely irrigated.

Georgetown and the immediate surrounding parts of the Demerara Coast represent 43 percent of Guyana's national GDP and 39 percent of its population[21]. This area was chosen as the focus of the study because of its relatively significant assets and the density of the population exposed to flooding.

ASSESSING FLOOD RISK

A detailed flood hazard map is usually necessary to assess historical flood levels, but none exists at a sufficient level of detail for the Georgetown area. We recommend that future assessments are based on measurement of actual flood events, but in the absence of this information, we were able to construct a sufficiently robust picture of the area's flood risk, using available data. (Exhibit 2)

To create this assessment, we developed a detailed Geographic Information System (GIS) map of the area prone to flooding. Developing this map relied on flood height and ground level surveys from the 2005 flood by the Lands and Surveys Commission and Oxfam. We obtained flood boundaries through the examination of satellite images on the relative elevation from nearby water bodies[22], modeling of water levels based on ground topography and interviews with local experts. Over this country flood hazard map, we mapped GDP and population density[23]. This map shows zones with different water heights from flooding, over five zones ranging from levels greater than 3 feet down to zero levels.

Building from census data, local verification and GIS mapping, we were able to distribute the value of different assets spatially across those zones in a detailed map. Further, we developed a marginality map[24] to locate the areas where the poverty index is greatest. This map is based on a set of livelihood and income variables including illiteracy, employment in the agricultural sector, existence of piped water/linkage to a sewer, electrification, school attendance, and overcrowding.

02

Depth data from the 2005 event allowed development of a flood map

Flood map for Georgetown
Zone boundaries, and flood heights, feet

Rain-driven flooding is historically a key risk: Georgetown has experienced five major rain-related flooding events since 1990. This flooding is the result of a combination of factors, including the large low-gradient river system that bounds Georgetown, the slow drainage of the coastal plain, and the location of much of the city's urban development below sea level

POTENTIAL ANNUAL LOSS OF UP TO $140M, AND NEGATIVE IMPACT ON HUMAN HEALTH

For 2030, the study estimated an expected annual loss of some $140m – a significant impact on assets, incomes and lives. This assessment is based on historical flood risk. If a single extreme event similar to that of 2005 occurred in 2030, this would result in additional losses of close to $1bn for the Georgetown area alone – more than a third of national GDP – and would expose more than 320,000 people to flooding. Clearly, flooding could be a significant deterrent to future growth if current levels of resilience are not suitably improved. Given uncertainty in future climate, we assessed losses from flooding based on three different climate change scenarios. (Exhibit 3)

LOSSES FROM TODAY'S RISK

To assess expected loss today and in the future, the test case methodology applies three primary components: hazard, asset, and vulnerability.

For hazard, we compared evidence from the flood of 2005, widely noted in assessments immediately following the event as the worst in Guyana's history, with local experience and historical assessments of flood severity in the past. For example, the country witnessed more than seven times the average January rainfall in 2005 – some 52 inches[25]. This was thus determined as a once-in-100 year event. Based on longitudinal precipitation data[26], flood depth measurements[27] and local interviews, we made the assumption of a linear correlation between precipitation and flooding in the mostly urban setting of Georgetown. In favor of this assumption is the fact that most flooding is of a local flash flood variety and is driven by physical design limitations of drainage infrastructure, rather than driven by river basin or soil composition. We accordingly developed baseline loss curves to plot the relationship between the frequency of an event against the economic damage it caused. Such loss curves form a key component of natural catastrophe modeling. ➔

Climate change scenarios

03

- **Predicting local climate is inexact given limited data. Therefore, 3 scenarios are developed**
  - Based on temp and precipitation predictions from 20 global climate models*
  - Based on a range of IPCC forecasts for sea level rise
- **While some regional climate models exist assessing at a higher resolution and smaller grid area than GCMs, the science behind these models is still developing**
- **Climate scenarios are later used to develop 3 hazard scenarios**

2030 scenarios	Description
1 **Today's Climate**	• **Historic rainfall and flood data used** to estimate flood frequency and height • Flood risk remains unchanged, while economic growth increases assets and incomes exposed to risk
2 **"Moderate" Change**	• **Monthly rainfall decreases by 5%,** as predicted by an average of 20 global climate models as likely outcome • Results in decreased flood heights
3 **"High" Change**	• **Monthly rainfall increases by 10%,** as predicted by the maximum of 20 global climate models for Guyana • Results in increased flood heights

* Extractions from 20 General Circulation Models (GCM) for area around Guyana, by Prof. Reto Knutti, ETH, Zurich

For residential assets, we used housing stock data supplied by the Ministry of Finance to estimate housing values. Short-term assets that can be damaged during a flood were estimated using 2005 data as an indication. Industrial, commercial and public assets were estimated in discussion with the Bureau of Statistics in Guyana. Agricultural assets were estimated using crop yields, price and total acreage. This collection of methods resulted in an estimate of asset value for the priority area at $5bn (in 2008 currency). Assuming assets grow in proportion to GDP growth, we estimate that asset value will be over $10bn in 2030 (in 2008 currency).

For the vulnerability component, our work relied on existing historical records and used an asset loss curve of the insurance industry to match a curve of multiple events, across the spectrum of severity and actual losses associated with those events, with historical records. The vulnerability of each type of asset is estimated in order to assess how much of each asset type (residential, industrial, commercial, public, or agriculture) would be lost given an event of a certain severity. Research of the Lands and Surveys Department in measuring 2005 flood heights will prove to be invaluable in helping the country prepare for future events, and enabled us to develop a new GIS flood map for our focus area to plot average ground elevation to various flood levels.

THE POTENTIAL IMPACT OF CLIMATE CHANGE

We relied on Global Circulation Models (GCMs)[29] to derive a range of possible outcomes using three possible scenarios: "today's climate" (relying on historical data), "moderate climate change" (showing 5 percent decrease in rainfall being the average of 20 GCMs) and "high climate change" (showing an increase in 10 percent in rainfall being the maximum of 20 GCMs used). Even if flood risk decreases, Guyana faces significant loss due to the current low level of climate-resilience.

Our calculations show the probable range of expected annual losses in 2030 ranging from 12 percent to 19 percent of GDP – or $1.1bn to $1.3bn in present value – depending on the climate change scenario. Exhibit 4 shows how annual expected loss in 2030 breaks down by asset type.

The assessment also shows that flooding from today's climate risk – even before accounting for the additional losses that climate change might bring – is a significant strain on the existing economy. Impact from current and future climate change goes beyond economic damage, as evidenced by the impacts on health from the great flood of 2005. More research is needed on the health impacts of climate change, but we expect flood impacts on lives and health to include increased prevalence of diarrhea, malaria, waterborne diseases and malnutrition. →

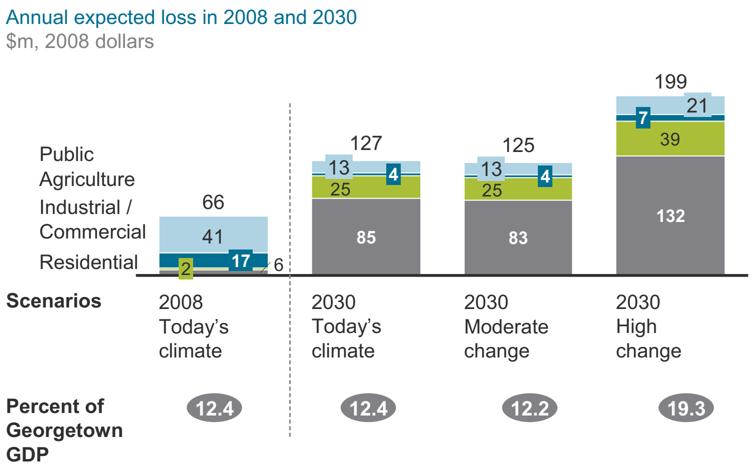
320,000

If a single extreme event similar to that of 2005 occurred in 2030, this would result in additional losses of close to $1bn for the Georgetown area alone – more than a third of national GDP – and would expose more than 320,000 people to flooding.

RAINFOREST | GUYANA

04

Expected losses across the different climate scenarios by asset type



A COST-EFFECTIVE PORTFOLIO OF CLIMATE RESILIENCE MEASURES IS AVAILABLE

In collaboration with local authorities, we prioritized and analyzed measures across the development spectrum (including infrastructural, technological, behavioral and financial measures) to address the current and future climate hazard risk. Local interviews and experience in implementing public works were critical in developing a shortlist of measures. We then tested these measures against their costs, and used a mix of analytical approaches to assess their economic benefits.

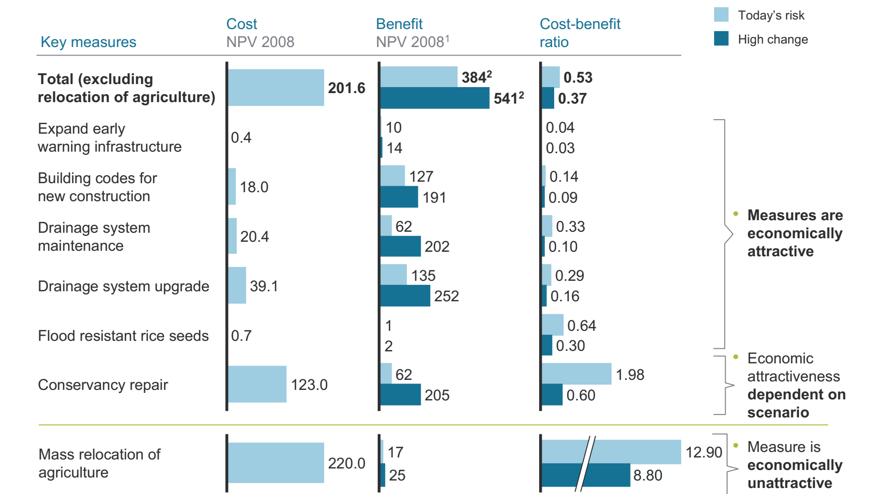
In collaboration with local authorities, we prioritized and analyzed measures across the development spectrum (including infrastructural, technological, behavioral and financial measures) to address the current and future climate hazard risk.

Some measures could be quantified in terms of their cost and benefit – including expanding early warning infrastructure, defining building codes for new construction, improving drainage system maintenance and upgrades, promoting flood resistant seeds, repairing conservancies, and mass relocation of agriculture out of flood zones. Other measures could be quantified in terms of cost, but with limitations in quantifying their economic benefit: these included repair and maintenance of sea walls, conservancy upgrades, flood-proofing of health clinics, improving sanitation and water supply, emergency response systems, and strengthening the primary insurance market.

For measures with a quantitative assessment on both costs and benefits, this approach produces a critical input into decision-making: a cost/benefit comparative analysis that identifies economically attractive options. Exhibit 5 summarizes these results.

05

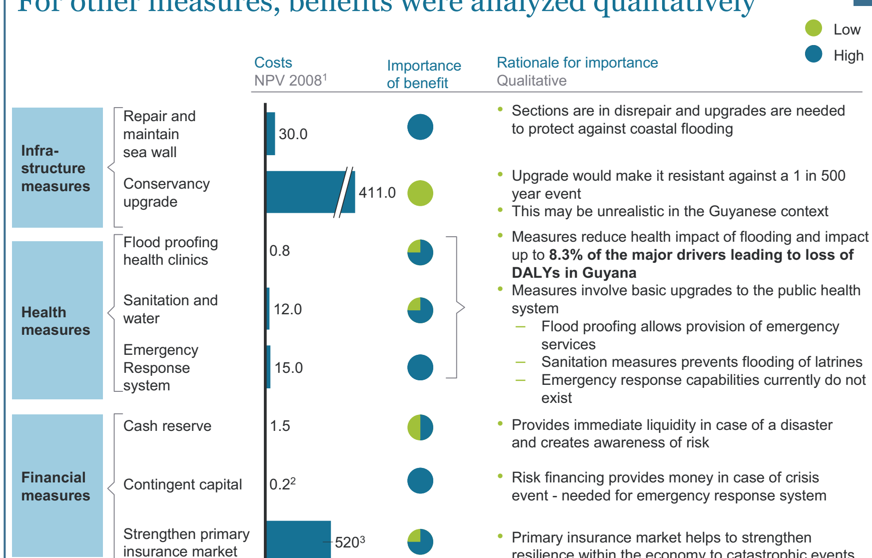
For measures where benefits were quantified, the ratio identifies economically attractive measures



1 Start date of measures 2015 assumed
2 Including synergies between measures

06

For other measures, benefits were analyzed qualitatively



1 Start date of measures 2015 assumed
2 Based on World Bank product
3 Based on total cost of insurance against a 20 year event, scale of the measure not defined

A qualitative evaluation of those measures whose benefits could not be quantified directly identified a further set of priority measures (Exhibit 6).

Despite the relative scarcity of quantitative information on climate risk in many developing countries, our work in Guyana demonstrates that given limited data availability, it is feasible to produce a quantitative assessment of risk and identify a set of measures, based on quantitative cost-benefit methods, to protect against that risk. The cost-benefit analysis approach helps to prioritize efforts and channel limited resources to the most effective actions to strengthen climate resilience. The approach adopted in Guyana could be replicated and applied in a range of other high-risk, data-scarce settings.

TEST CASE ON HULL, UK – FOCUS ON RISK FROM MULTIPLE HAZARDS

When flooding struck many parts of the United Kingdom in the summer of 2007, the city of Kingston upon Hull ("Hull") on England's North Sea coast was amongst the worst affected locations. Some 35,000 people – 15 percent of the population – evacuated from their homes. The flooding affected 7,800 houses, 1,300 businesses, and scores of public buildings, including some 100 schools in the city and its surrounds. The Hull City Council estimated the total cost of the flood to be around at $300m[29].

These events cast a spotlight on Hull's vulnerability to one climate hazard, freshwater flooding. But the city's low-lying coastal location, at the confluence of the Rivers Hull and Humber, puts it at particular risk from two other hazards to which the UK is exposed: wind storms and coastal flooding from sea-level rise. While wind storms are fairly homogenous even more inland, storm surge is of acute risk given Hull's coastal location and a key risk to consider.

Hull serves as a useful test case to assess how the risk of these multiple hazards might affect the economy of the UK and its most vulnerable regions. Given that Hull, the UK's twelfth largest city, is an economically deprived area currently under regeneration, it also serves as an instructive example of how measures to protect against climate risk can strengthen economic development.

This appendix summarizes the test case undertaken in Hull, highlighting the risk the city faces, the magnitude of the potential loss assessed, and the measures that could avert that loss and promote climate-resilient development.

The study drew on an extensive body of existing research. Analyses by the UK Environment Agency[30] provided particularly valuable input to our calculations.

RISK FROM MULTIPLE HAZARDS – FLOOD, WIND, SEA LEVEL RISE

Historically, the UK has suffered extensive flooding caused by extreme rainfall events: its annual average loss from such

FLOODED RIVER | ENGLAND

freshwater flooding has amounted to $2.8bn a year in the last few years. As the windiest country in Europe, the UK is also vulnerable to wind storms[31], with the English North Sea coast in particular facing a high risk of storm surge – water that is pushed towards the shore by the force of the storm winds. Major storm surge events have routinely struck this coast once a decade for the past 50 years; the most significant event in living memory took place on January 31, 1953, when coastal defenses were breached in more than 1,000 places[32]. Exhibit 1 summarizes the range of hazards Hull faces and highlights the three hazards assessed in this test case. →

01

Focus on flooding, winter storms, and storm surge due to their large, combined impact on urban activity

Low impact
High impact
Examined further

Hazards	Impact	Comments
Flooding (river or flash		• Biggest damage to the UK with ~$2.8b damage, likely to increase due to climate change
Winter storms		• High threat to the UK with approximately $1.4m damage, likely to increase due to climate change
Storm surge/ sea level rise		• Significant risk on the east coast of the UK
Heat wave		• While UK not at such a high risk compared to central/southern Europe, 2003 heat wave with impacts on mortality; very likely to rise with climate change
Snow		• Not frequent in UK, but with severe disruption for economic activity in case of event; likely to decrease with climate change

- While heat waves and snow storms are important risks to the United Kingdom, the focus of our work was on flooding, winter storms, and storm surge/sea level rise
- The area of Hull was examined due to its high vulnerability to all three hazards and high concentration of assets, incomes, and lives

"Today's climate" puts Hull at significant risk from both freshwater and coastal flooding. The climate change scenarios for the test case, drawing on modeling from the UK Climate Impacts Programme (UKCIP02) and other literature[33], found that this risk could be exacerbated in three ways over the next two decades and beyond:

- A 5-10 percent increase in annual rainfall to 2030 could increase the frequency and severity of extreme precipitation events, heightening the risk of freshwater flooding
- An increase in the frequency and severity of North Sea wind storms would cause more severe storm-surge wave heights
- Gradual sea level rise would compound the risk of coastal flooding

It should be noted that London, despite lying on the River Thames and near the North Sea coast, does not face significant risk from multiple hazards. The Thames Barrier is projected to succeed in protecting the city from a once-in-1000-year storm surge event until and perhaps beyond 2030 .

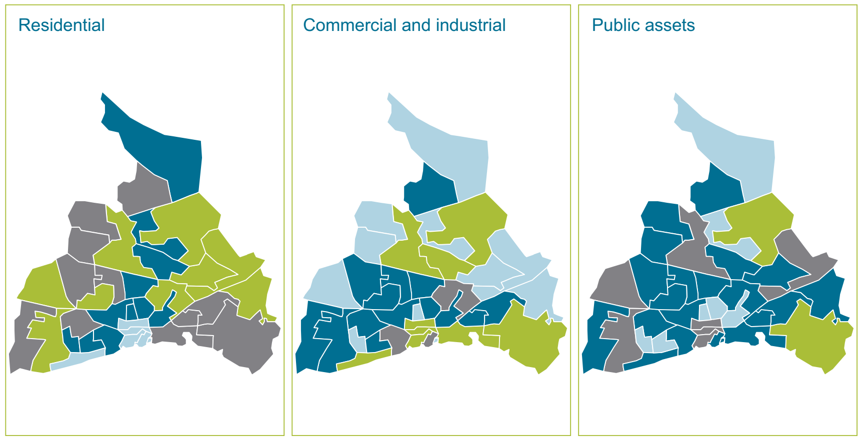
POTENTIAL ANNUAL LOSS OF UP TO $100M

In 2005, Hull generated Gross Value Added (GVA), or economic output, of $7.4bn (2005)[36]. Working closely with the Hull City Council, the study put together a detailed picture of the city's economy today, its most likely development path to 2030 based upon regeneration plans, and the expected losses that could be caused

02

Spatial distribution of assets at risk

By postcode area



03

Climate change scenarios

- Key uncertainties exist around climate change resulting in highly variable predictions and outcomes
  - Future development of emissions and global warming uncertain
  - Local impact of climate change on weather variables uncertain
- Development of 3 different scenarios required to account for these uncertainties

2030 scenarios	Description
1 **Today's climate**	• No change in climate, historical events used as baseline
2 **"Moderate" change**	• A2 scenario as underlining global emission scenario • Varying parameters for each return period, (storm surge height increase 16-26 cm; increase in extreme precipitation up to 3.3%
3 **"High" change**	• Worst case assumptions within the hazard modeling used (storm surge height increase of 31-42 cm; increase of 8.3% in extreme precipitation)

by the climate risks identified. The focus in Hull was on the economic value of the assets at risk to the identified hazards. To assess the spatial distribution of assets at risk we relied upon existing data available for the city of Hull. (Exhibit 2)

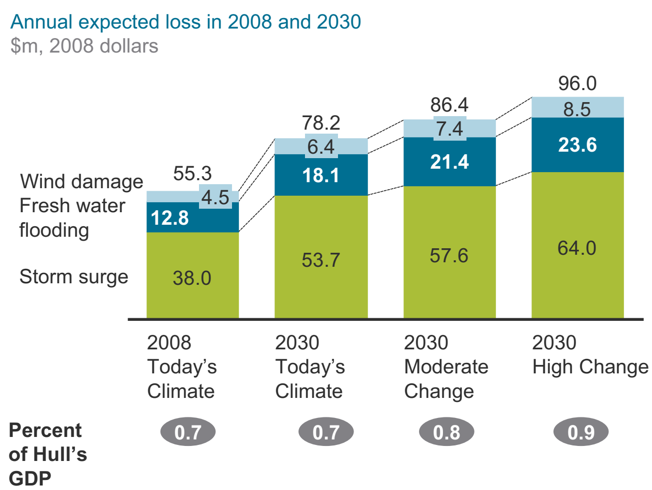
While human lives may potentially be affected by climate change, historically they have not been at significant risk and hence, were not the primary focus of the test case. Exhibit 3 outlines the three climate scenarios developed for Hull to reflect the uncertainty in future climate.

LOSSES FROM TODAY'S RISK

The total annual expected loss for Hull from all hazards in 2008 is more than $50m – a significant figure, though less than 1 percent of the city's GDP. The greatest asset value at risk today is amongst residential buildings, and is concentrated in several particularly vulnerable postcodes. Coastal flooding from storm surge accounts for the large majority (70 percent) of this loss. Interestingly, the average annual expected loss from wind, $4.5m, exceeds the average annual expected loss from the surface water proportion of the fresh water flooding, slightly below $4m. Despite these figures, recent experiences with surface water flooding have caused the city to focus efforts on improving defenses against this hazard – with arguably insufficient attention given to the risk of damage from wind. This highlights the importance for decision-makers of being continually cognizant of the total climate risk faced by their location.

04

Expected losses across multiple hazards



THE POTENTIAL IMPACT OF CLIMATE CHANGE

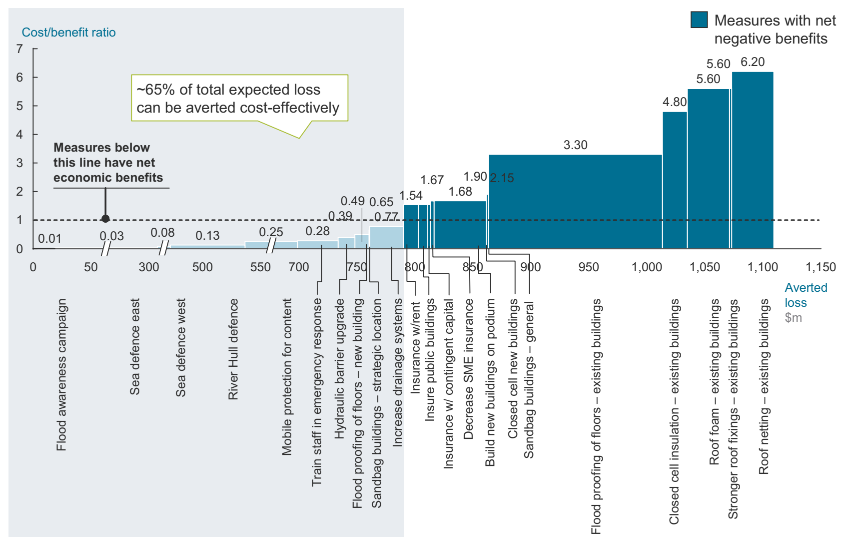
By 2030, the moderate climate change scenario could increase the risk across all asset classes by 10 percent compared to the current climate, while high climate change could increase it by as much as 20 percent. This figure is still below 1 percent of the city's GDP, reflecting the relatively advanced climate resilience and adaptation measures already in place in the UK. Climate change would increase the threat across all hazards, and exacerbate losses amongst all asset classes. For example, high climate change would lead to an expected annual loss in 2030 of about $50m for residential buildings – compared to $40m under the "today's climate" scenario.

Even under the high climate change scenario, though, the majority – 58 percent – of the expected loss in 2030 is from current climate risk to current assets. Asset growth to 2030 is the secondary driver, accounting for 27 percent of the loss to 2030, while climate change, even under this scenario, accounts for just 15 percent of 2030 loss. The implication for decision-makers is that Hull will benefit from a focus on strengthening current defenses and heightening the climate-resilience of the city's regeneration path – and that these will be valuable precautionary measures against a range of possible climate change scenarios, even the most extreme. Exhibit 4 outlines the summarized results of expected annual losses across hazard type as a result of running existing Swiss Re probabilistic loss models given asset value in Hull. ➔

05

The initial portfolio of responses cost-effectively averts much of the expected losses

HIGH CLIMATE CHANGE



A COST-EFFECTIVE PORTFOLIO OF CLIMATE RESILIENCE MEASURES IS AVAILABLE

What, then, can decision-makers in Hull – and in other locations in the UK faced with comparable climate risk – do to address the risk and shape climate-resilient development and regeneration paths? Using the cost-benefit methodology described in the main report, a range of measures was evaluated, including policy measures, such as flood-proofing requirements for new buildings and flood awareness campaigns; engineering measures, such as sea defenses; and risk-transfer measures, including insurance. To evaluate these measures we worked with local agencies and drew on existing evaluations if possible (for example in the case of sea defenses which have been evaluated by the EA).

This evaluation of measures translated into a cost curve (Exhibit 4) that shows that the annual expected loss for Hull, even in a scenario of high climate change to 2030, can be partially averted through measures that have net economic benefits. These include flood awareness campaigns, emergency response training, improvement and repair to Hull's existing sea and river defenses, and mobile protection for household contents (through provision of large, waterproof, resealable bags to residents). We did not identify any cost effective measures against wind damage nor estimate synergies due to time limitations; therefore, all of the expected loss cannot be averted.

However, decision-makers assembling a portfolio of measures to strengthen climate resilience need to consider other factors in addition to the cost curve, including synergies and dis-synergies between measures, and the potential for low-frequency, high-severity events such as one-in-100 year floods. Hull has the opportunity to implement measures with net economic benefits to address much of the range of hazard frequencies.

For events with a very low frequency, insurance measures – to transfer rather than directly prevent the expected loss – may prove a cost-effective component of the portfolio. These measures include improving insurance penetration of public buildings, many of which are currently uninsured in Hull, and expanding an existing City Council scheme to encourage tenants in public housing to take on personal household contents insurance. The last measure would especially target the lower income population, therefore increasing resilience among the more vulnerable part of the population.

Although the UK, even in vulnerable locations like Hull, is better adapted to climate risk than most of the other locations studied, extreme weather nonetheless has the potential to cause significant economic damage –which climate change could heighten. Decision-makers have the opportunity to put together an effective portfolio of climate-resilience measures, at limited cost. The key, though, will be to avoid a reactive focus on the most recent weather disasters and instead to assess all climate risks holistically – preparing both for the full set of potential hazards, and for a range of event frequencies. ❍

TEST CASE ON SOUTH FLORIDA, USA – FOCUS ON RISK FROM HURRICANES

In 1992, Hurricane Andrew devastated the southern tip of Florida, pounding the coast with sustained winds of 175 miles per hour and bringing along storm surges, water that is pushed towards the shore by the force of the storm winds, of up to 17ft[37]. When the storm abated, it left $38bn of damage in its wake[38] – a testament to how quickly infrastructure can be destroyed.

Situated in the extreme south east of the United States, the Florida peninsula juts out between the Atlantic Ocean and the Gulf of Mexico. With its famous sunshine and pleasant weather, it is no wonder that 90 percent of the state's population and 75 percent of its GDP (including $875bn in property value) is situated along the coast . This makes Florida particularly vulnerable to hurricanes – hurricanes that will grow in intensity as climate change alters sea level and sea temperatures[40].

This appendix summarizes the test case focused on South Florida, which investigated the climate- related hazards the area faces, assessed the potential damages of these hazards, and identified and evaluated potential measures to alleviate these losses.

In conducting the study, we drew on an extensive body of existing research – including historical data and the knowledge of climate scientists, local property appraisers, and mitigation experts. There is no shortage of information available. But it is our hope that, by applying a total climate risk management approach to this information, we can help build further understanding of the measures that are needed to protect South Florida's economy and people from future climate hazards. ➔

SOUTH FLORIDA MOST AT RISK FROM HURRICANES

The study focused on the risk posed from hurricanes, the hazard that poses the greatest danger to South Florida over the next twenty years. There is considerable historical risk from this hazard: between 1992 and 2005, 30 tropical cyclones impacted Florida, more than any other US state[41]. Climate change could increase in the intensity of future hurricanes, thus increasing the damage they wreak. Exhibit 1 summarizes the range of hazards assessed and the rationale for focusing on hurricanes.

Although Florida as a whole is at risk from hurricanes, Broward, Miami-Dade and Palm Beach Counties at the state's southern tip are particularly susceptible. In addition to having been hit by the greatest number of hurricanes, these counties represent some of the largest population and economic centers (in the State), making them the natural choice for the focus of our study (Exhibit 2).

POTENTIAL ANNUAL LOSS FROM HURRICANES OF MORE THAN $30BN – 10 PERCENT OF THE THREE COUNTIES' GDP

South Florida is already at risk of major economic loss from hurricanes. Drawing on Swiss Re's extensive historical loss database and probabilistic loss models, we

01

Focus on hurricanes due to their overwhelming impact on society

Legend: Low impact; High impact; Examined further

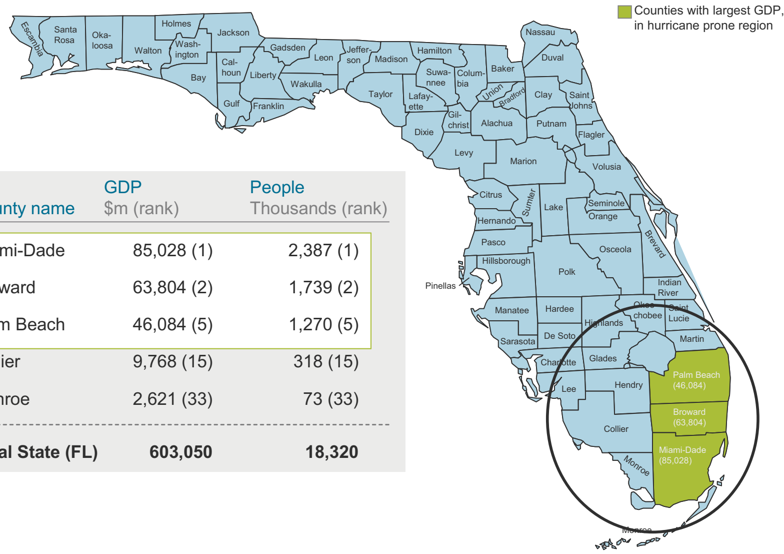
Hazards	Impact	Comments
Hurricane		• Hurricane damage likely to increase with climate warming • Primary cause of flooding and responsible for the majority of hazard induced damages
Sea level rise		• Expected to be a critical issue in long term; less potential for impact in 2030 timeframe • Storm surge and water supply are likely to be adversely impacted, particularly in southern Florida
Temperature increase		• Drought events may be exacerbated by an increase in global temperature. However, – Precipitation forecasts[1] not expected to change and impact on humidity unclear – Measures already in place to handle high temperatures

- While sea level rise and temperature increase are important risks to Florida, the focus of our work was on hurricanes
- More hurricanes hit Florida than any other State in the USA (30 between 1992-2005)

1 Intergovernmental Panel on Climate Change (IPCC) 2007, (for medium scenario of GHGs)

02

The case study area is home to some of the most populated and economically successful counties in the State



County name	GDP $m (rank)	People Thousands (rank)
Miami-Dade	85,028 (1)	2,387 (1)
Broward	63,804 (2)	1,739 (2)
Palm Beach	46,084 (5)	1,270 (5)
Collier	9,768 (15)	318 (15)
Monroe	2,621 (33)	73 (33)
Total State (FL)	**603,050**	**18,320**

Although Florida as a whole is at risk from hurricanes, Broward, Miami-Dade and Palm Beach Counties at the state's southern tip are particularly susceptible. In addition to having been hit by the greatest number of hurricanes, these counties represent some of the largest population and economic centers.

Climate change scenarios

03

- **High level of uncertainty around predicting hurricanes**
  - Many climate factors play a role in the development and strength of hurricanes
- Narrowed focus and scope to address only **hurricane intensity and height of sea level rise**
- Using expert input, **three climate scenarios were developed**
  - Intensity forecasts based on the link between sea surface temperature and wind speed
  - Sea level rise projections were based on projections across two ice flow outcomes

2030 scenarios	Description
1 **Today's climate**	• **Current climate data used** as the baseline for wind speed and sea level • Frequency of hurricane events based on historical and is not varied
2 **"Moderate" Change**	• **Wind speed increase of 3% and sea level rise of 0.08m** • Uses an average of various wind speed to sea surface temperature relationships • Storm surge increases due to sea level rise
3 **"High" Change**	• **Wind speed increase of 5% and sea level rise of 0.24m** • Uses a maximum wind speed to sea level surface relationship • Storm surge increases further

calculated that the wind, storm surge, and rain associated with hurricanes are today responsible for annual economic loss totaling $17bn in the three counties – more than 8 percent of GDP. Using historical GDP to project growth rates by county, we estimated that their GDP would rise to $316bn in 2030. Using a model built on historical storm data in the region, we used this baseline 2030 GDP to calculate the annual potential loss from hurricanes in 2030 under three climate change scenarios: "today's climate", "moderate climate change", and "high climate change".

The scenarios were built in order to enable economic loss assessments under significant uncertainty about how climate change might influence hurricane activity in South Florida. Although there is general scientific consensus that hurricanes will increase in intensity as a result of increased sea level and sea surface temperature, there is less certainty around what this specifically would mean for southern Florida. Academic studies estimate that a one degree Celsius rise in sea surface temperature might trigger an increase in wind speed – a proxy for hurricane intensity – anywhere between 2 and 8 percent.

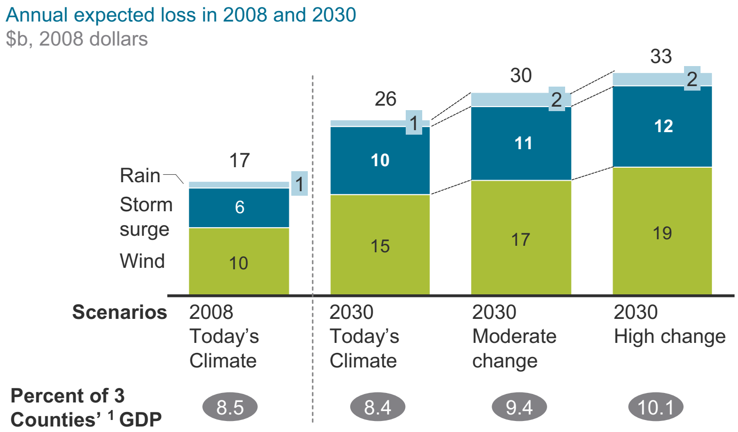
The future severity and frequency of cyclones are difficult to predict due to oceanic phenomena. Cyclical phenomena including decadal oscillations, El Nino Southern Oscillation, La Nina and Madden Julian Oscillation all historically are assessed as impacting frequency of hurricanes. The number of CAT 3-5 occuring during cold phases is less on average than the number of CAT 3-5 storms during warm phases[42]. However, recent history suggests that cyclone intensity, as indicated by the Tropical Power Dissipation Index (PDI), has more than doubled in the last 35 years[43]. Furthermore, sea surface temperature plots against the PDI with a correlation coefficient of r-squared 0.69[44]. Because sea surface temperature is expected to increase by 2.6 degrees Celsius in the next 100 years[45], cyclone PDI is expected to increase as a result of climate warming. Although, of the components of PDI, cyclone intensity and not frequency is expected to increase[46], note that the effects of frequency changes on damages are linear, while the effects of wind speed are exponential.

The "moderate" and "high" climate change scenarios are modeled on increased average wind speeds of 3 and 5 percent respectively. Exhibit 3 summarizes the various climate change scenarios analyzed during the test case

Based on these assumptions, the study calculated that a "moderate" climate change scenario will result in an annual expected loss of about $30bn, while the "high" scenario would bring the loss to more than $30bn – more than 10 percent of the three counties combined GDP (Exhibit 4), and over 3% of the State's forecasted GDP. ➔

04

Expected losses across multiple hurricane components



1 2008 Moody's

COST-EFFECTIVE MEASURES AVAILABLE TO AVERT MUCH OF THE LOSS – BUT LARGE RESIDUAL LOSS REMAINS

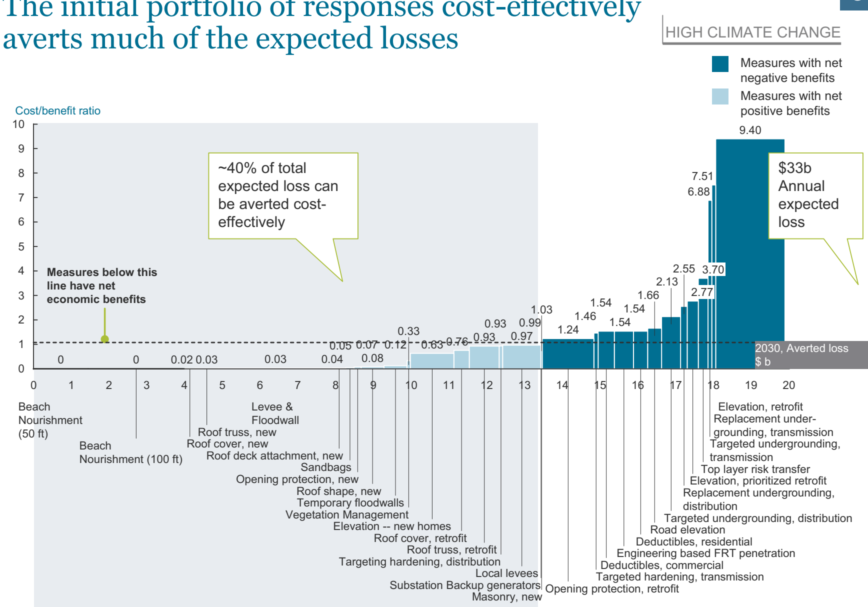
Given the large value at stake, what can be done to mitigate this risk? The study considered a range of infrastructural, technological, behavioral, and risk transfer measures, and identified several that should play a core part of a strategy to manage South Florida's hurricane risk:

- Beach nourishment – the extension of beaches into the ocean, to absorb storm surge. This measure is highly beneficial relative to cost, and has proven successful in other coastal states
- New home improvement. There are many measures which fit into the new home improvement category – including elevating the home on concrete piles and securing its roof with metal straps and nails – most of which can be achieved through building code establishment and enforcement.
- Vegetation management – essentially, proactively managing trees that might be knocked onto buildings during hurricanes. This measure comes at low cost and reduces the risk of windborne branches increase asset damage or business interruption.
- Barriers to water intrusion. There are many different cost effective measures to address the hazard of flooding, ranging from barriers protecting one door to barriers protecting entire communities
- Top layer risk. A risk transfer measure, this addresses low frequency, high risk events such as one in 100 year hurricanes.

The cost curve shows that Florida could offset close to half of its annual expected loss under the climate change scenarios through measures that have net economic benefits. Nonetheless, the cost curve also demonstrates a significant proportion of the loss – some 40 percent of it – is unlikely averted

The initial portfolio of responses cost-effectively averts much of the expected losses

05



We drew on expert interviews and quantitative data to develop a cost curve for these and other measures identified. The cost curve shows that Florida could offset close to half of its annual expected loss under the climate change scenarios through measures that have net economic benefits. Nonetheless, the cost curve also demonstrates a significant proportion of the loss – some 40 percent of it – is unlikely averted (Exhibit 5). This reflects the fact that Florida's urban development is concentrated along the coast; averting a greater part of the expected loss to 2030 may require a shift in economic development patterns towards less vulnerable parts of the state.

South Florida already boasts many "best in class" approaches to manage hurricane risk, including highly advanced emergency response systems. Florida is also a pioneer in designing and enforcing building codes (particularly for wind resistance) and has been applauded for its innovation in this area. Nonetheless, as the risk continues to rise, it is critical that decision-makers keeps a close gauge on the extent of the value at risk, and the relative performance of the full range of measures to protect that value. ❍

TEST CASE ON SAMOA – FOCUS ON RISKS CAUSED BY SEA LEVEL RISE

Samoa is a small island state in the South Pacific, with a population of less than 200,000 concentrated on two islands, Upolu and Savai'i. Some 70 percent of Samoa's villages lie along the coast, and one in three buildings is located below four meters elevation. This makes the country and its people highly vulnerable to flooding from tropical cyclones. The damage wrought by Cyclone Ofa, for example, which struck Samoa in 1990, amounted to some 37 percent of GDP.

This appendix summarizes the test case undertaken in Samoa, highlighting the coastal flooding and salinization risks posed by sea level rise, the magnitude of the potential losses, and measures that could reduce the country's vulnerability.

The study drew on an extensive body of existing research. In particular, the team acknowledges Mark Bakker, Scott Izuko, Prof. Patrick Nunn, Prof. Adrian Werner, and Neil White for many valuable conversations and help in identifying useful analyses and tools. Moreover, we would like to thank the Government of Samoa, in particular the teams of Tu'u'u Ieti Taule'alo at the Ministry of Natural Resources and Environment and of Iulai Lavea at the Ministry of Finance, for the support provided to this initiative. Finally, we would like to thank Sergio Margulis from the World Bank for his collaboration in setting up the team's scoping mission to Samoa.

RISK OF COASTAL FLOODING AND SALINIZATION FROM SEA LEVEL RISE

This study focuses on sea level rise caused by climate change. Sea level rise may magnify the damage caused to low-lying communities by storm surge events, and thus represents a serious threat to Samoa. In addition, sea level rise may cause salt water to encroach into the fresh groundwater aquifer, an effect known as salinization. This could compromise freshwater sources currently tapped for human use, threatening both human health and coastal agriculture.

Although, historically, Samoa has also suffered wind damage from tropical cyclones, we have chosen not to include wind damage in this test case. While the intensity of tropical cyclones is generally expected to increase in years to come as a consequence of rising water temperatures, the impact of climate change on their frequency is as yet unknown. The uncertainties are not trivial. Some researchers have even forecasted a decrease in the number of tropical cyclones in the Northern Pacific[47].

Sea level rise, however, certainly presents a threat to low-lying communities, mainly due to its impact on coastal flooding. Based on Samoa's vulnerability profile, the test case was therefore geared towards sea level rise and its consequences for coastal flooding and salinization.

COASTAL FLOODING

Historically, Samoa has suffered extensive damage from flooding, especially along its coast. Future coastal flooding events are expected to increase significantly in severity, driven by sea level rise. Note that change in regional mean sea level is the result of the interaction of several global as well as regional effects, including the local climate and oceanography as well as effects that are not related to climate. For example, sea level rise in Samoa that is driven by climate change is exacerbated by geological subsidence at a rate of between 0.1 and 1.7mm per year due to long-term cooling of these volcanic islands[48].

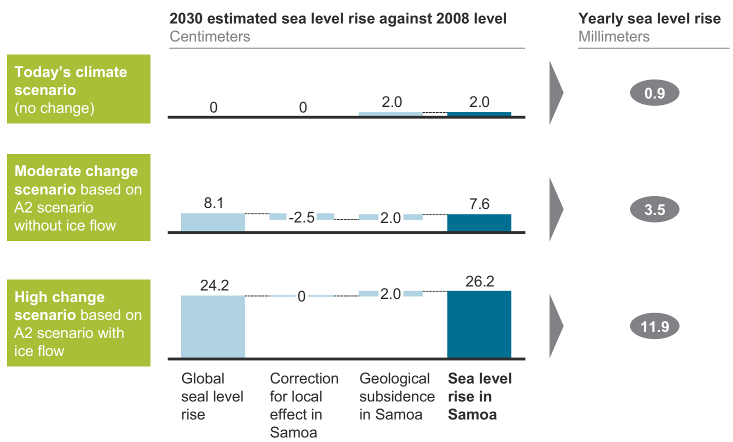
These multiple global and regional elements were folded into our sea level rise scenarios for Samoa based on "moderate" and "high" climate change. In the "high" scenario, sea level could rise by up to 26.2cm by 2030 (Exhibit 1).

To estimate the impact of sea level rise on the occurrence of coastal flooding events, we combined these scenarios with a model of return periods for storm tide events. The latter was based on a state-of-the-art statistical analysis of the data

01

Scenarios for long-term sea level rise; in high climate change, sea level might rise by up to 26.2 cm by 2030

Sea level rise scenarios in Samoa by 2030 compared to 2008



SOURCE: IPCC 4th AR; Rahmstorf (2009); CSIRO; Dickinson (2007)

recorded at the Apia tide gauge. The combined model accounted for astronomic tide, storm surge, wave set-up, and wave run-up in addition to long-term sea level rise as components of the coastal flooding hazard during a storm event .

SALINIZATION

Currently, salinization affects a few wells on the Fale'alupo peninsula of western Savai'i. However, Samoa is potentially vulnerable to increasing salinization as around one-third of human water use in Samoa is supplied from groundwater. The salinity of coastal groundwater is determined by several factors, including the rate of pumping and average annual rainfall, but this study focused on the effect of sea level rise. Assuming no significant changes in rainfall patterns, our model showed that sea level rise might cause an inward retraction of the freshwater lens by about 30 meters on Upolu by 2030 in the high scenario. The effects are likely to be much more significant in the longer term: in the high scenario, the freshwater lens might move by up to about 60 meters on Savai'i and by up to about 160 meters on Upolu by 2100, potentially contaminating additional freshwater sources. Salinization is highly sensitive to other climatic factors such as changes in rainfall. Global circulation models predict – at the extreme – a decrease in average annual rainfall by 10 percent in Samoa. Under this assumption, the freshwater lens on Upolu might move by up to 60 meters in the high scenario by 2030 (Exhibit 2).

In the high scenario and assuming no changes in precipitation levels, up to 2 percent of the population could be affected by salinization in 2030. A precise quantification of the economic damage caused by salinization is not yet possible as Samoa currently lacks a monitoring system for well and borehole water salinity. However, it appears that at least for the two main islands of Samoa the expected economic damage due to salinization is significantly smaller than that due to coastal flooding. By comparison, salinization risk is much higher in other, smaller islands such as atolls, or even the smaller islands in Samoa. The approach we have developed for Samoa could easily be applied to those cases. →

POTENTIAL ANNUAL LOSS OF 9 PERCENT OF GDP

We focused the test case on economic value in Samoa. Thanks to the development of a national tropical cyclone plan – including an early warning system – human lives are no longer considered to be significantly at risk from climate risk. Working closely with Samoa's authorities, we developed a very detailed picture of the country's current assets. Specifically, we determined the value at risk in coastal areas by taking into account precise location and elevation of buildings and roads (Exhibit 3). Asset value was projected to grow at the same rate as national economy until 2030. For reference, in 2008, Samoa generated a GDP of $510m.

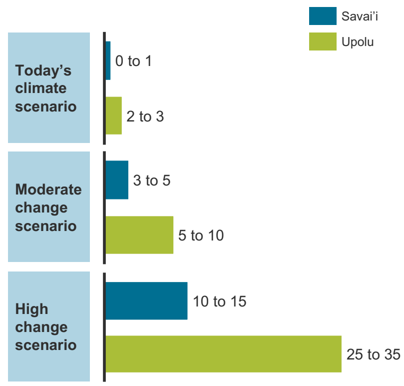
LOSSES FROM TODAY'S RISK

In 2008, the annual expected loss from coastal flooding amounts to $25m, corresponding to 5 percent of the country's GDP. Damage to commercial buildings represents the greatest share of losses, corresponding to approximately 60 percent of all losses; this is a disproportionally high share, as commercial buildings represent only 50 percent of all asset value. Conversely, residential assets are exposed to disproportionally low risk – suffering 25 percent of the damage – despite representing 30 percent of total asset value.

02

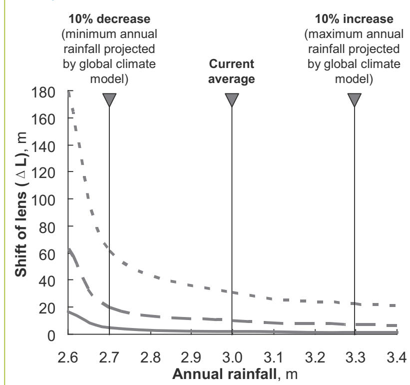
The freshwater lens is expected to retract by ~ 30 meters in Upolu and ~10 meters in Savai'i by 2030

Horizontal retraction of freshwater lens due to sea level rise, in meters



Both depth and location, particularly distance from coast) will affect the salinization of individual wells

However, salinization is highly sensitive to changes in average annual rainfall



A 10% decrease in rainfall could double the expected horizontal retraction of the freshwater lens in the high change scenario

SOURCE: ECA analysis; CMIP3 global models

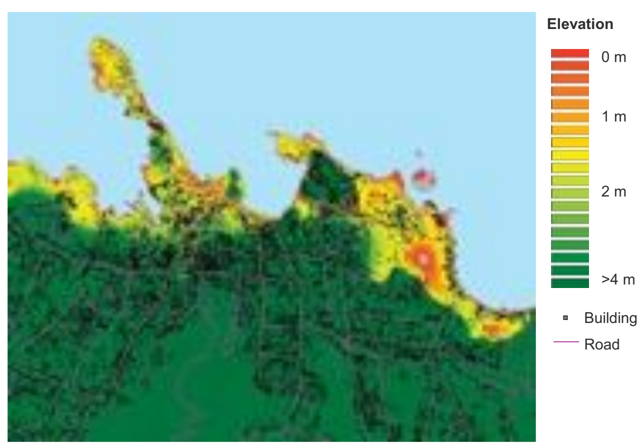
03

Highly granular geographic information has been used to segment assets according to their elevation above sea level

Approach

- Starting point was a digital map of Samoa with contour lines (2m lines in coastal areas)
- In a second step, a more granular segmentation of coastal areas was obtained by using state-of-the-art GIS software
- Finally, geo-coordinates of buildings and roads, were used to determine the asset exposure to coastal flooding risk

Elevation map of central Apia



SOURCE: Samoan Ministry of Natural Resources and Environment

THE POTENTIAL IMPACT OF CLIMATE CHANGE

In the high climate change scenario, sea level rise will significantly impact the risk of coastal flooding. For instance, the frequency of an event with the intensity of cyclone Ofa may increase from once every 50 years in 2008 to once every 20 years in 2030. This scenario could result in annual expected loss from coastal flooding of $80m, or 9 percent of GDP.

Historically, Samoa has suffered extensive damage from flooding, especially along its coast. Future coastal flooding events are expected to increase significantly in severity, driven by sea level rise.

By 2030, even in the moderate climate change scenario, the risk across all asset classes may increase by more than 100 percent compared to today, while under high climate change this increase may even amount to 200 percent.

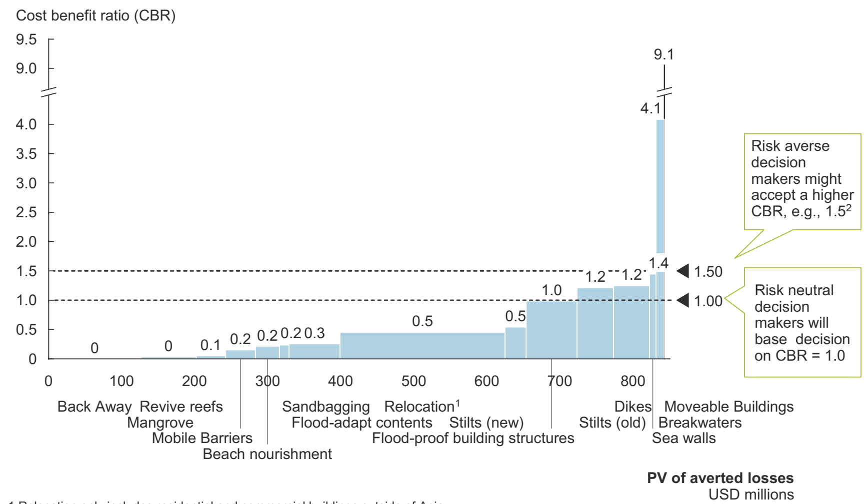
A COST-EFFECTIVE PORTFOLIO OF CLIMATE RESILIENCE MEASURES IS AVAILABLE

Despite the growing risk posed by climate change, there are a number of adaptation measures Samoa could put in place to minimize the risk of damage and increase its resilience to climate threats. The test case developed and evaluated a comprehensive list of measures, which include infrastructure measures, such as moving all houses out of harm's way; technological measures, such as installing mobile flood barriers in high-risk areas; behavioral measures, such as restricting all new buildings to at least a four-meter elevation. In a second step, we considered financial measures (including risk transfer) as a solution to cover that share of the risk which cannot be physically averted in a cost-efficient way. According to our methodology, measures were analyzed in terms of costs and benefits. The resulting cost curve is shown in Exhibit 4.

In order to identify an optimal portfolio of measures, we compared the cost-benefit ratios of the considered measures across the different scenarios. This sensitivity analysis confirmed the hypothesis that, in Samoa, the economic attractiveness of measures does not depend in an essential way on the climate scenario (Exhibit 5) ➔

04

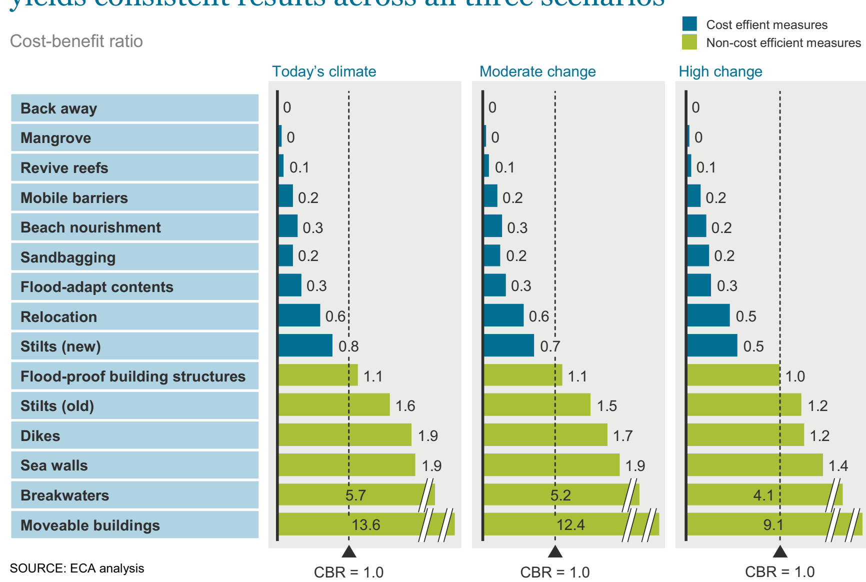
The overall cost-benefit assessment shows a variety of options to reduce coastal flooding annual expected loss



1 Relocation only includes residential and commercial buildings outside of Apia
2 For example, a cost benefit ratio of ~1.5 is implicitly accepted by customers purchasing an insurance contract with a loss ratio between 60 and 70%
SOURCE: ECA analysis

05

Prioritization of measures based on cost-benefit analysis yields consistent results across all three scenarios



SOURCE: ECA analysis

The cost curve for measures to adapt to coastal flooding risk shows that there are several cost-efficient measures. It does not, however, take into account synergies and dis-synergies between the various measures. For example, building a coastal sea wall or a coastal dike are mutually exclusive options (i.e., dis-synergies are 100 percent). Considering such effects, we identified the most cost efficient portfolio of measures. In the case of flooding risk in Samoa, our analysis shows that even in case of the high climate change scenario, approximately 50 percent of the yearly expected loss of 2030 can be averted by implementing a portfolio consisting of four cost-efficient measures: restricting all new buildings to at least a four-meter elevation ("back away"), planting a protective mangrove buffer, flood-proofing contents, and using mobile barriers.

Although not considered explicitly in this analysis, some measures are likely to add extra value by averting losses from natural hazards not directly related to climate change. For example, mangrove barriers will reduce tsunami damage risk.

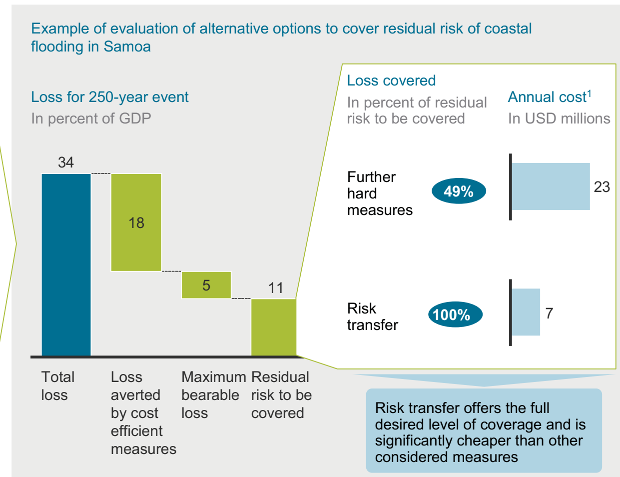
In our analysis, we mainly accounted for the economic costs and benefits of adaptation measures. However, other qualitative aspects should be considered while defining a portfolio of adaptation measures. Such qualitative aspects might include constraints due to cultural heritage or availability of required skills. For instance, in Samoa, enforcing "back-away" by means of a mandatory land use plan for the entire country could spark a series of conflicts between central authorities and Matais (local chiefs).

Risk transfer is the most efficient way of providing additional coverage for low-frequency events

06

Approach to risk averse decision making

- In a **risk averse setting**, decision makers select adaptation measures by taking into account two main components:
  - Objective/risk-neutral net value
  - Subjective assessment of costs and benefits
- The results of subjective assessment of costs and benefits should include two main elements:
  - A **reference event** to be considered while selecting protection (e.g., a 250-year event)
  - The **maximum bearable loss** for the reference event – this can be expressed as a percentage of GDP e.g., 5%)



1 Estimate based on Swiss Re rule-of-thumb

SOURCE: ECA analysis

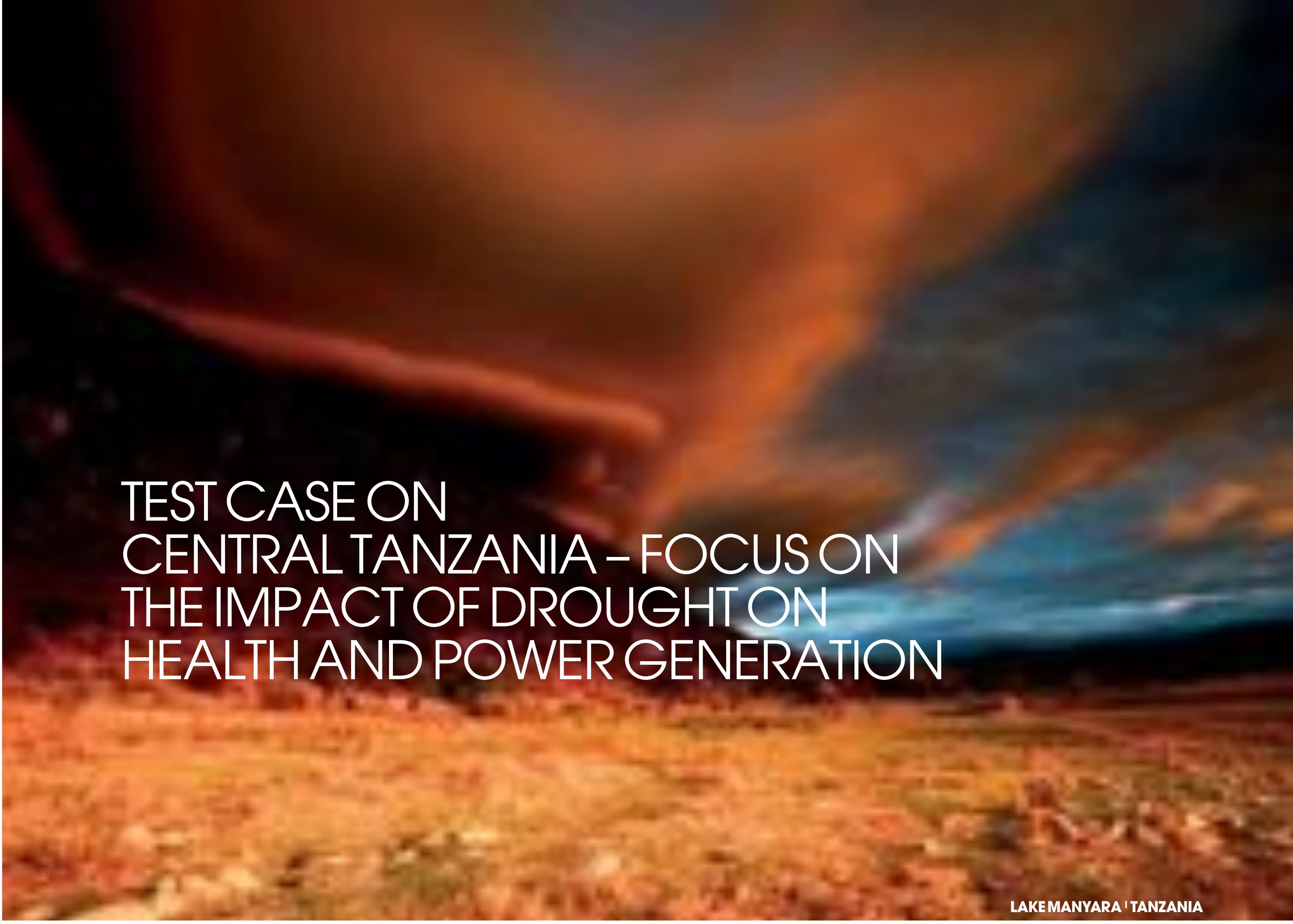
Therefore, we believe that soft measures such as incentives may be more effective to encourage development further from the coastal hazard zone.

As cost-efficient adaptation measures cannot cover the entire spectrum of events, alternative solutions to deal with the residual risk should be considered. For events occurring very infrequently, risk transfer measures might provide a cost-effective component of any portfolio of measures, transferring rather than directly preventing expected losses.

Decision makers must decide what share of that residual risk should be shouldered by Samoa, as opposed to transferred to the capital market or averted through other measures. Since such a decision is driven by budget/capital constraints, risk aversion can be expressed as a percentage of GDP – this would correspond to the maximum single event damage to be carried by Samoa expressed in percentage of GDP. We compared risk transfer to other possible adaptation measures, assuming a risk aversion threshold of 5 percent of GDP and coverage for a 250-year event. The result confirmed that, under these assumptions, risk transfer may present the most efficient solution by being both cheaper and more comprehensive in coverage than the other measures considered (Exhibit 6).

Samoa benefits from ample high ground on which to seek protection from flooding, and relatively abundant sources of freshwater. Nonetheless, sea level rise may cause significant economic damage, with the risk of this damage increasing over time due to climate change. More detailed models of anticipated climate change, and more detailed data on potential salinization, are necessary to understand the full likely impacts. Even so, Samoan decision-makers have the opportunity to assemble an effective portfolio of climate resilience measures with net economic benefits. The key, though, will be to assess all climate risks holistically – preparing both for the full set of potential hazards, and for a range of event frequencies to prepare against the total climate risk. ❍

TEST CASE ON CENTRAL TANZANIA – FOCUS ON THE IMPACT OF DROUGHT ON HEALTH AND POWER GENERATION



LAKE MANYARA | TANZANIA

Tanzania, a low income country in East Africa, has experienced six major droughts over the past 30 years. The most recent, in 2006, ravaged agricultural production and the single event is estimated to have cut GDP growth by 1 percent[50].

The test case, however, focused on two specific drought impacts that are of particular concern in Tanzania:

- Human health, which is threatened by malnutrition and the spread of cholera and other infectious diseases caused by shortages of fresh water
- Power generation, which in Tanzania depends predominantly on hydro-electric plants; in 2006, for example, the country faced severe power rationing because of the shortfall of generated power

Because these two impacts were not specifically modeled in the other test cases undertaken by the Working Group, the Tanzania case also provided an opportunity to test the broader applicability of the "total climate risk" framework and methodology to both private sector actor concerns and the larger and nascent research topic of health impacts from climate change.

This appendix summarizes the test case, which was undertaken in the drought-prone central region of Tanzania. It outlines both the risk posed by climate to health and power generation, and the measures available to address the risk.

The test case drew on an extensive body of existing research, including a range of expert interviews (see Acknowledgements). In particular, we would like to thank the Honorable Frederick Sumaye – former Prime Minister of Tanzania, for his gracious collaboration.

RISK OF MORE SEVERE AND MORE FREQUENT DROUGHTS

We assessed a wide range of hazards before focusing on drought risk. Exhibit 1 summarizes the hazards identified within Tanzania and the supporting rationale for choosing droughts for deeper analysis.

To construct three climate risk scenarios to 2030 ("today's climate" "moderate climate change," and "high climate change"), the study employed 10 downscaling climate change models created by various international universities and institutions, all compiled by the University of Cape Town[51]. Overall, for the entire country, there is an average expectation of an →

increase in rainfall. However, unlike the rest of the country, the central region – under the "moderate change" scenario – is projected to experience a 10 percent decrease in the amount of annual rainfall, and 25 percent increased variability in the amount of annual rainfall. These changes would lead to more severe and frequent droughts. Under the "high change" scenario, rainfall would fall by 20 percent and variability increase by 50 percent (Exhibit 2). The fact that Regional Climate Models (RCM) offer a higher level of geographic granularity as compared to Global Circulation Models (GCM) is of particular importance in Tanzania. GCM findings predict an increase in 2030 rainfall for the entire country, however RCM results show that the central region – that already faces droughts and is the location of most hydropower reservoirs – is expected to experience a reduction in annual precipitation. Additionally, we tested the hypothesis that the shape of the precipitation distribution curve would vary among the different climate change scenarios – which was facilitated by the availability the RCM results.

The central region, comprised of the Dodoma, Singida, and Tabora regions, is primarily rural and the majority of its 4.4 million inhabitants are poor subsistence farmers. The population is exposed to a range of serious drought-affected health risks. For example, the National Bureau of Statistics issued a report in 2003 that revealed that 19 percent of children under 5 had suffered from diarrhea in the two weeks preceding the survey.

The central region is also critical in terms of hydropower generation, with major dams situated on the Rufiji River which

01

Focus on drought due to the large impact on health and power production in the central regions of Tanzania

Legend: Low impact; High impact; Examined further

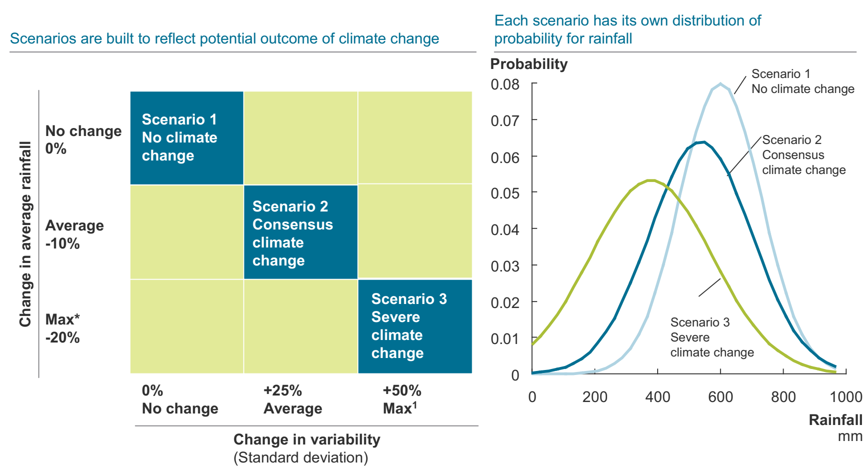
Hazards	Impact	Comments
Drought	High impact	• Droughts having significant impacts in several areas: – Health (Increases the prevalence of water related diseases and malnutrition) – Hydro-electric power production (responsible for ~60% of Tanzania's power generation) • Increased frequency and severity of droughts in the central regions expected due to climate change
Floods	High impact	• Floods having substantial impact in several regions of Tanzania across multiple areas – infrastructure, agriculture production and health • Forecasted to increase in severity and frequency due to climate change
Sea level rise	Low impact	• Tanzania has 800 km of coast line and multiple islands where impact of sea level rise can already be seen (salination of wells, destruction of infrastructure) • The size of the impact is limited by 2030 timeframe: – Sea not expected to rise significantly till 2050/ 2100 – Tanzania not located in an hurricane zone

- While floods are important risks to Tanzania, the focus of our work was on droughts and its impact on health and electric power production
- Sea level rise is of high concern in Tanzania but, was not studied due to the lower size of the impact in the 2030 timeframe

1 Intergovernmental Panel on Climate Change (IPCC) 2007, (for medium scenario of GHGs)

02

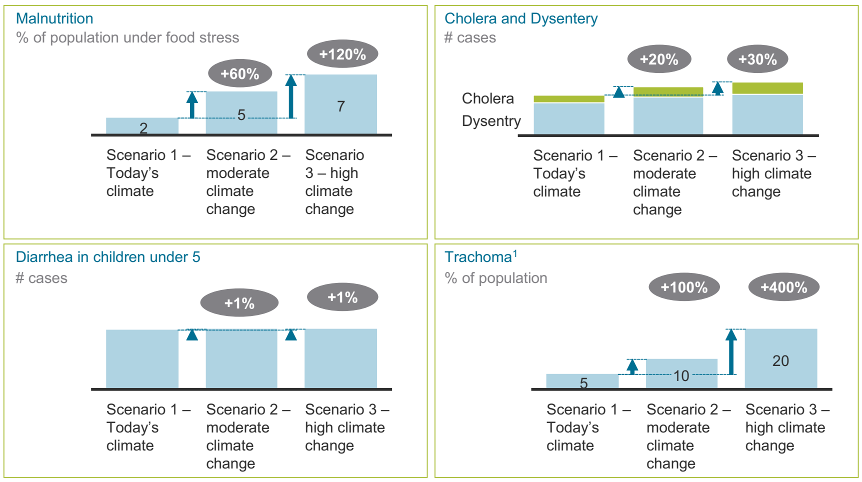
Three scenarios were built on potential climate change for the central regions of Tanzania



1 One before the worse scenario

Climate change scenarios highlight incremental health risks for 2030

03



1 No regression has been generated, this estimate is based on expert interviews at Ministry of Health

flows through the region: the Kidatu and Mtera dams, which are located in or near the central region, contribute 50 percent of the Tanzania's hydropower production capacity[52].

HEALTH: IMPACTS AND ADAPTATION MEASURES

The most relevant drought-related diseases were identified through interviews with doctors, Health Ministry officials, and international NGOs including the International Trachoma Initiative and the World Food Program. Of all locally relevant diseases, five were identified as the most drought-related: malnutrition, trachoma (an infectious eye disease that causes blindness), dysentery, cholera, and diarrhea. While recognizing many factors drive disease prevalence and occurrence, our work focuses on isolating a single driver.. For example for dysentery, we discovered reasons why dysentery is increasing despite a decrease in rainfall including the decline in the availability of water for personal hygiene and the use of stagnant pools of water for washing and food preparation in times of drought. As with other sectors, our objective was to provide a fact driven, proven methodology to assess adaptation and not set our directives on what measures work best to address certain disease modalities. We asked ourselves "how would a minister of health think about the impact of climate change on their existing strategies" to drive our analysis.

Historical rainfall data from the Tanzanian Meteorological Agency (TMA) was correlated with historical numbers of cases of key diseases and with crop supply and demand imbalances (as a proxy for malnutrition). This analysis allowed us to predict the additional number of people affected by those diseases in the future when drought will increase in frequency and severity. The initial findings are built on limited data , but were shared and test with local experts. These findings should not be taken as a prediction but simply raise the need for further, more detailed research on the relationship between health and climate change.

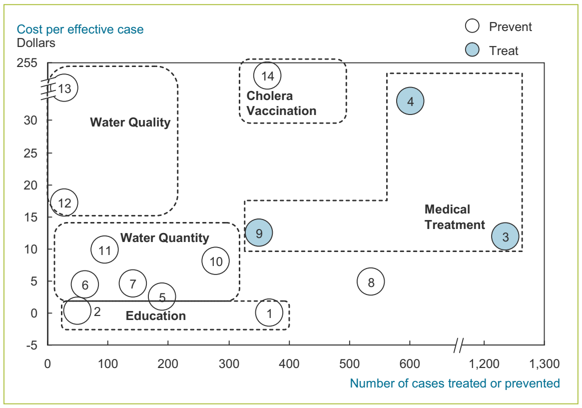
TODAY'S RISK AND THE IMPACT OF CLIMATE CHANGE

The inhabitants of the central region already face significant exposure to the drought-related diseases identified. By 2030, even if there is no change in drought frequency or intensity, it is projected that 5 percent of the region's population will suffer hunger from poor yields. Additionally, 5 percent of the population will suffer from trachoma, with high numbers of cases of cholera, dysentery, and almost 200.000 children under 5 suffering from diarrhea.

By 2030, under the moderate climate change scenario, a 10 percent decrease in average rainfall is projected to cause a 60 percent increase in the proportion of the population under food stress, and significant increases in the number of cases of cholera and dysentery. Trachoma cases could double in number. The high climate change scenario would worsen this impact, particularly for trachoma (Exhibit 3). →

Diarrhea, Dysentery, Cholera – Adaptation measures

04



Diarrhea, Cholera, Dysentery Measures

1 Educational program to encourage good hygiene and sanitation
2 Educational program to encourage breastfeeding
3 Administration of Oral Rehydration Therapy
4 Targeted administration of antimicrobials
5 Build basic covered wells with pipes
6 Rainwater harvesting 1,000L
7 Rainwater harvesting 2,500L
8 Build ventilated pit latrines
9 Administer zinc supplements
10 Build 100 MM boreholes + pump + engine + 40,000L holding tank + distribution pipes
11 Rainwater harvesting 20,000-45,000L for schools and other public buildings
12 Mechanical filtration of water
13 Chemical filtration of water
14 Cholera vaccination

A PORTFOLIO OF MEASURES TO PREVENT AND TREAT DISEASE AND MALNUTRITION

The study analyzed appropriate measures that could be implemented to protect against drought-related health risks cases. Measures were classified as either prevention (such as cholera vaccinations) or treatment (such as oral rehydration therapy for cholera patients). Calculations of the cost of each measure included the costs of various components of the program and the likely efficacy of the intervention. For example, for trachoma, the cost analysis for the mass administration of preventative antibiotics included such costs as the purchase, shipping, storage and distribution of storage, but also the overhead costs such as training and salaries.

The estimated number of each disease that would be prevented with each measure was determined by the number of cases of the disease predicted for 2030 in the moderate climate change scenario, discounted by the penetration rate (an estimate of the proportion of the target population that could realistically be reached by each measure) and the efficacy rate (using published percentages for each measure). Exhibit 4 shows the output of this analysis for diarrhea, cholera, and dysentery measures. Estimates for these calculations came from local administrators of similar programs, or from internationally recognized literature.

The analysis reveals clusters of types of measures for diseases (including water availability, water quality, education, vaccination and treatment). Each such cluster will be effective in treating or preventing a different number of cases, at a different cost per case. A similar exercise can be conducted for measures to address malnutrition (including farmer support, food aid, education and food storage measures). Although cost is obviously not the only criterion in assembling a public health strategy, this exercise provides a comparison of the cost-effectiveness of various measures, as input into such a strategy. These estimates are intended to start a dialogue and are not single point estimates. For example in trachoma, significant debate exists on the impact of education in terms of number of cases prevented – further research should be conducted before aligning funding strategies.

POWER GENERATION: IMPACTS AND ADAPTATION MEASURES

RISK OF CUTS IN ENERGY SUPPLY

Our analysis revealed that in 2030, Tanzania will rely on hydropower for more than 50 percent of its capacity, with 95 percent of this hydropower located in the central region. Drought will decrease water flow in rivers and lead to a lower availability of hydropower. The Tanzania Electricity Supply Company (Tanesco) would therefore need to use thermal (natural gas and coal) sources more frequently and at higher cost than for hydropower (and which would also result in an increase in global greenhouse gas emissions). Alternatively, Tanesco would need to cut electricity supply, affecting industrial production and hence GDP – as happened during the 2006 drought.

To assess more precisely the impact of droughts on power generation, historical rain was correlated with historical power production at Kidatu, the biggest power plant in the country. The analysis revealed that 1 GWh can be produced for every 2mm of rain in the central region. This result was then extrapolated to all hydro plants in central Tanzania, which provided an understanding of the amount of hydropower available in the different climate change scenarios. It was estimated that although the energy reserve margin by 2030 could be as high as 26 percent with no climate change, it could fall to 12 percent under moderate climate change, or 0 percent in the high climate change scenario. Typically a reserve margin under 15 percent is considered a risk.

This low availability of hydropower is leading to significant additional cost for the country. This includes the additional cost of power generation from using thermal technologies which are more expensive than hydropower, the cost of using individual diesel generators during electricity cuts and losses of production for the 40 percent of firms that do not their own generators.

In the high climate change scenario the expected losses will lead to a 1.7 percent decrease in national GDP in 2030. Even in the moderate climate change scenario, GDP will decrease by 0.7%, solely as a result of the climate-change induced droughts (Exhibit 5).

Efficiency provides cost-free solution
The cost curve for power measures illustrates that it is possible to close most of the expected shortfall in power production by implementing energy efficiency measures, such demand reduction (encouraging less or more careful usage by residential and commercial sectors) at a negative cost for the country. Additionally, reducing spillage at hydro stations and therefore improving the load factor of hydropower could enable a significant increase in power supply for almost zero cost. Lastly, building new power plants and reducing losses associated with the transmission of electricity could be considered, but at higher costs. A power cost curve (Exhibit 6) compares these measures by cost and impact in closing the projected shortfall.

The incremental impact of climate change on health will clearly necessitate additional spending to prevent and treat cases of relevant diseases. However, →

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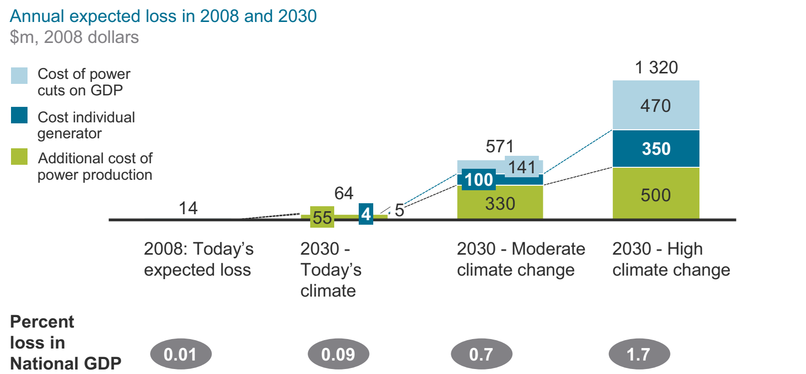
Expected losses across scenarios due to lower availability of electricity

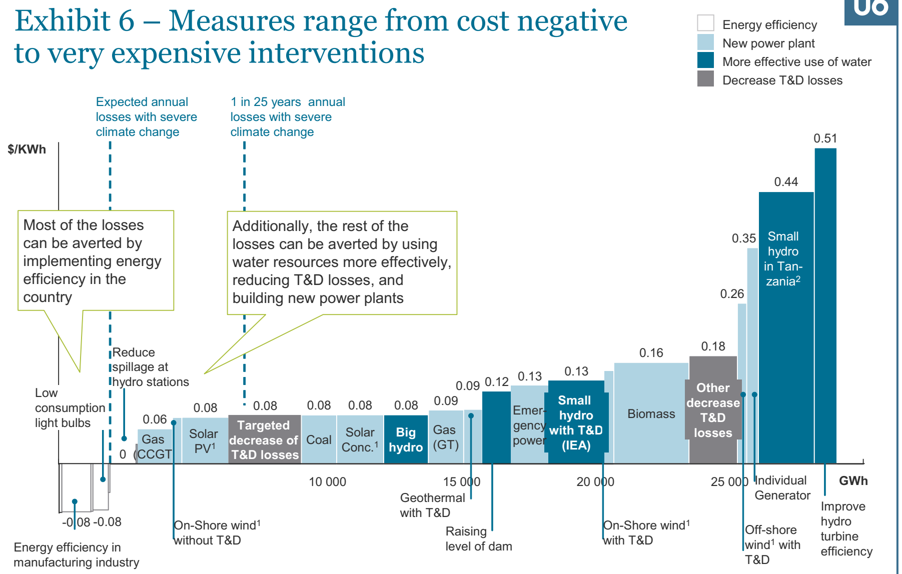


- **Without climate change**, the **available electricity** would be **sufficient** to avoid GDP losses
- However, **decreased rainfall** in both climate change scenarios **will lead to losses in GDP of up to 1.7%**

1 Current dollars
2 60% of entities have their own generator

WHITE LAVA FLOW | TANZANIA

Exhibit 6 – Measures range from cost negative to very expensive interventions



1 IEA Hypothesis on decrease of wind and solar cost by 2030 have been applied
2 Based on TANESCO: "Small hydropower investment Opportunities in Tanzania"
3 For cost of energy efficiency measures, $ savings from lower electricity consumption are accounted, whereas for all other measures, only direct cost of implementation are accoutned

it will not always be easy to distinguish adaptation from development spending on health. For example, water access measures suggest the ability to prevent thousands of cases of trachoma, dysentery, diarrhea, and cholera, but this could be considered good health policy with or without climate change. Health spending needs to be more proactive in the context of climate change, whereas it has tended to be more reactive, suggesting the need for better cooperation between government ministries and civil society. Tanzania appears well positioned to benefit from careful assessment of the costs implications from climate change on health and to plan measures accordingly.

Successful power adaptation will require creative solutions to account for national growth, international regulation, and our changing climate. This study points to outstanding questions: What effect does upstream usage of water have on hydropower production? How will it evolve? How will carbon regulation evolve for developing countries? And therefore, what are the implications of diversifying with thermal power plants versus renewable energy? The study also point to areas where more information and is needed. A hydrology study could be launched to understand more about the link between rainfall and hydropower production, for example, while further refinement of the costs of each measure will help to clarify priorities between measures. Despite the uncertainties, "no regret" energy efficiency measures could be implemented immediately. ❍

Tanzania will rely on hydropower for more than 50 percent of its capacity, with 95 percent of this hydropower located in the central region. Drought will decrease water flow in rivers and lead to a lower availability of hydropower

APPENDIX 2: METHODOLOGY GUIDE

The Economics of Climate Adaptation Working Group developed a detailed methodology for assessing the total climate risk in a target area (a country, region, or city), and to evaluate and prioritize the measures available to improve that area's climate resilience. This report sets out the steps in the initial version of that methodology, which was applied and tested in the country case. These test cases validated the methodology's core steps across a diverse set of climate risks, impacts and development stages, but also highlighted areas for expansion in later versions of the methodology.

The aim of this appendix is assist decision-makers in applying the methodology in their own countries, thus providing a quantitative basis for national and local discussions on adaptation and climate-resilient development. The appendix provides detail on the objectives and scope of the methodology, and on practical steps to apply it. It also outlines next steps for further development of the methodology.

OBJECTIVES AND GUIDING PRINCIPLES OF THE METHODOLOGY

The Working Group had four overarching objectives for the methodology:

1. Create holistic analyses linking climate hazards to adaptation measures: bring together a sequence of analyses to quantify the risk from climate hazards based on climate change scenarios; assess the costs and benefits of adaptation measures; and consider qualitatively the non-economic benefits of such measures

2. Perform consistent comparison of adaptation: apply a comparable methodology across a global sample of hazards, and across sectors, thus informing decision-makers about adaptation trade-offs between economic sectors

3. Apply the methodology to both the developed and the developing world: shape a methodology that would apply equally both in the developed world, where portions of the required analyses already exist; and in the developing world, where key data sets need to be created – for example, physical hazard models connected to IPCC projections, asset and income census data, and vulnerability of infrastructure

4. Weave these components into a clear and relevant tool for decision-makers: this methodology guide is intended to assist decision-makers in replicating the approach outlined in this report, in their own countries, regions and cities

In line with these objectives, the methodology followed a set of guiding principles which are linked to the tangible outputs of the analyses:

- Assess overall climate risk: evaluate total current and future risk from climate hazards – that is, not only the expected additional risk from climate change but also risks due to current climate risks – and develop loss models with multiple climate change scenarios to reflect uncertainty. A decision-maker must respond to the total risk facing society and not only to the incremental risk. (Note that, for the purposes of the test cases described in this report, the one or two most important climate risks were selected for each location; a full application of the methodology would assess the risk from all relevant hazards.)

- Be transparent: prepare to share the underlying steps, assumptions and tools with local decision-makers, but also with a global audience of stakeholders

- Build modular tools: ensure that the methodology – the models for both risk assessment and cost-benefit evaluation of adaptation measures – allows for modification and refinement based on future findings from researchers (for example, new insights into how climate change affects local hazard patterns)

- Focus across sectors: quantify economic loss "bottom-up", by including detailed risk assessments of physical assets and incomes across sectors of the economy

SCOPE OF THE METHODOLOGY

This methodology was developed primarily as a tool for national and local decision-makers. It is focused on the apparent gaps in existing analyses, where the expertise of the Economics of Climate Working Group could best provide a contribution to advancing knowledge and practical action on climate adaptation. This focus is reflected in key decisions and assumptions governing the scope of the methodology.

EXPECTED LOSSES FROM CLIMATE RISKS WERE ESTIMATED FOR SPECIFIC HAZARDS AND LOCATIONS

Expected losses and the costs of adaptation are two different, complementary ways of examining the impact of climate change (Exhibit 1). Expected loss is the amount of damage likely to occur in a defined time period (for example, one year). It is calculated as a function of the severity and frequency of the climate hazard, the value of assets (for example, buildings) exposed to the hazard, and the vulnerability of those assets to the hazard. A proportion – sometimes nearly all – of the expected loss can be addressed by adaptation measures. The cost of adaptation, then, is the investment required in adaptation measures aimed at minimizing the damages from future climate hazards. Hence, the total cost of climate change is the sum of the cost of adaptation and any residual expected losses not averted by the adaptation measures.

Other studies, such as the UNFCCC report described earlier, attempt to measure the total costs of adaptation nationally or globally – a critically important as the world begins to develop effective adaptation strategies, for example as a key input into the Copenhagen negotiations (Exhibit 2). However, the methodology described is not intended as a tool to calculate such global adaptation costs. Rather, it focuses on expected losses and adaptation measures at the local level, under the practical assumption that climate change will have significant local impacts requiring the urgent focus of local decision-makers.

Replicable analytical approaches will ensure consistency, but require streamlining assumptions

A key decision in designing the methodology was to focus on analytical approaches that would be highly replicable. These included:

- Scenario planning to address uncertainty
- Assumptions used to forecast economic and population growth
- Adaptation measures assessed using a cost-benefit analysis

SCENARIO PLANNING TO ADDRESS UNCERTAINTY

To ensure that this methodology is accessible and replicable, the Working Group addressed future climate uncertainty by developing discrete scenarios based on publicly available scientific research. Note that integrated advanced approaches such as decision trees or chaos theory could be applied to more accurately assess the full range of uncertainties. However, in light of the pressing need for rapid decisions and actions in adapting to climate change, these sophisticated models are subject to the law of diminishing returns – they may provide only a slightly more precise answer for significantly more effort invested. In addition, these complex models risk decreasing the replicability of analyses and, more importantly, may become less transparent and traceable to decision-makers who are not climate experts. →

ASSUMPTIONS USED TO FORECAST ECONOMIC AND POPULATION GROWTH

The Working Group chose to simplify assumptions on economic and population growth to increase transparency of the model, rather than leveraging general equilibrium methodology concepts. General equilibrium models incorporate the impact of economic investments – including adaptation measures – on future GDP and population growth. These models try to estimate the feedback loop dynamically in a system. However, while we acknowledge that the adaptation measures we assess are likely to feed back into future growth, we chose to make economic and population growth independent of investment choices. Critically, the advantage of using simplifying assumptions such as these is that practical and understandable models are more likely to gain acceptance among non-experts.

ADAPTATION MEASURES ASSESSED USING COST-BENEFIT ANALYSIS

The Working Group chose to assess measures using a societal cost-benefit analysis methodology. Cost-benefit ratios may not be perfect indicators of the value of adaptation measures: for example, the inclusion of various costs and benefits in net present value cash flow calculations are subject to debate. Nonetheless, cost-benefit approaches are commonly used in national decision-making, and are a recognized form of presenting information to support trade-off decisions. In applying cost-benefit analysis to adaptation measures for the

01

Conceptual relationship between expected loss from climate risk and the costs of adaptation

ILLUSTRATIVE

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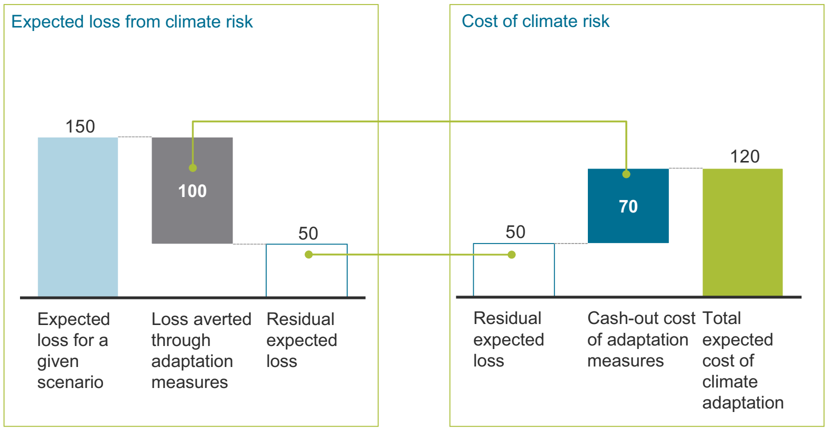

Expected loss = the amount of damage likely to occur in a defined time period

The total cost of climate change = sum of the cost of adaptation + any residual expected losses not averted by adaptation measures

02

The costs of adaptation are uncertain: estimates vary substantially and are incomplete

Upper bound / Lower bound / Primary research

	Adaptation cost estimates, € bn year: Lower bound	Upper bound	Total	Timeframe	Methodology
UNDP (2007)	70	19	89	2015	Per World Bank study but includes: revised "climate proofing" estimates; costs of adapting poverty reduction strategies and improving disaster responses
Oxfam (2007)	41	0	41	Present	Per World Bank study but scaled to include: scaling up of costs of NGO projects and immediate adaptation needs of developing countries
UNFCCC Global estimate (2007)	36	99	135	2030	Examination of adaptation in five sectors: – Infrastructure – Agriculture, forestry and fisheries – Water supply – Human health – Coastal zones
UNFCCC LDCs estimate (2007)*	23	32	55	2030	
World Bank (2006)	8	27	34	Present	Analysis of current financial flows and estimates exposure of each group of flows to climate risk and cost of "climate-proofing" those exposed flows
Stern review (2006)	3	28	31	Present	Updated exposure and climate-proofing cost estimates assumes less ODA at risk and a lower cost to "climate-proof" flows

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test cases profiled in this report, the Working Group was careful always to evaluate these measures in light of the current as well as future climate.

The end product of this analysis is a cost-benefit curve comparing the selected adaptation measures, rather than a recommendation to implement specific measures. It should be emphasized that this methodology is designed to support local decision-making processes, rather than to provide a prescriptive answer on which adaptation measures a location should implement. A cost-benefit analysis is only one of several decision-making criteria, including the flexibility of measures, capital expenditure constraints, cultural preferences, and the value placed on ecosystems, among others. The local expertise of decision-makers is therefore critical in evaluating which measures are finally most attractive, taking into account all of these factors.

FOCUS ON ANALYTICS, NOT POLICY CHOICES

It is beyond the scope of this methodology to evaluate policy decision-making. Tactically, this means that while the approach described in this report considers approaches to implementation and assesses barriers to implementing the measures that appear most positive in a cost-benefit analysis, it does not address policy aspects of adaptation. A large body of work by policy-focused analysts is available to address the wider range of issues associated with adapting to climate change risks, such as recent policy guidance for adaptation issued by the OECD[53].

PRACTICAL GUIDE TO THE METHODOLOGY

In each of the test cases profiled in this report, a 12-16-week on-site effort was undertaken to apply the analytical steps of the methodology. Although a full application of the methodology in a location may take somewhat longer, it is intended to generate robust information on climate risk and adaptation measures within a short space of time. The inquiry for each location is centered round five questions:

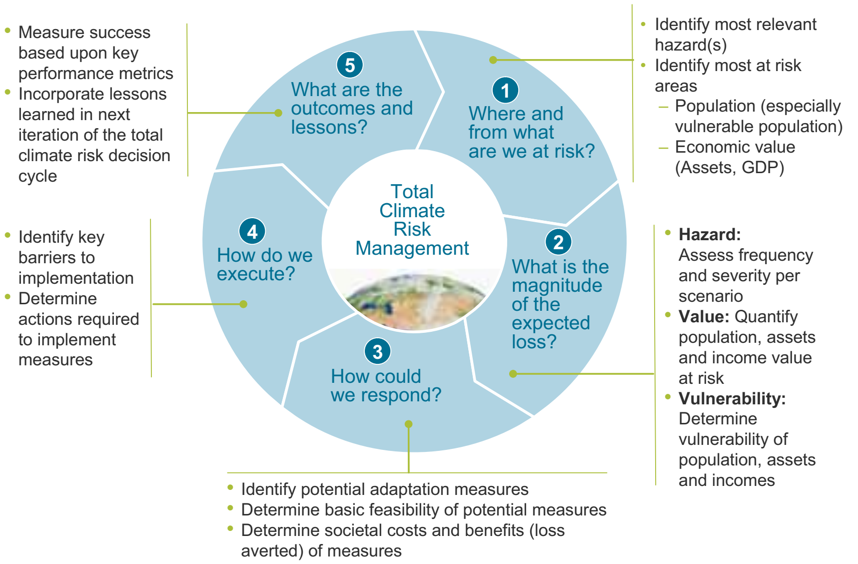
1. Where and from what are we at risk?
2. What is the magnitude of expected loss?
3. How could we respond?
4. How do we execute?
5. What are the outcomes and lessons?

This methodology guide focuses on the first three, analytical, steps.

The test cases assessed only the most important hazard or hazards in the locations studied (for example, drought in Maharashtra, India) and focused on particular regions or cities. Nonetheless, the methodology is intended to be applicable at the national level, making it possible to assess the full range of hazards affecting a country – hazards that in most cases will differ significantly across different regions within that country. ➔

Country case study methodology

03



What follows is an overview of the steps in the methodology, to guide decision-makers through the analysis and to emphasize the potential applications of the methodology to a broader set of hazards and wider geographic scope (Exhibit 3). Despite uncertainties and the overlapping effects of climate change in the economic, environment and social sectors, these steps and calculations are executable even in settings where data is often sparse.

QUESTION 1: WHERE AND FROM WHAT ARE WE AT RISK?

There are four methodological steps to answer this question.

1. **Collect all available data on climate**
   Where possible, local historical data sets including temperature, precipitation, and individual events should be compiled. These data sets should be placed in context within global or regional historical data. Where data is not available, profiles from other, similar regions can be used as analogies, or a survey of local inhabitants can be conducted.

2. **Leverage the perspectives of the scientific community to select the hazard(s) with the biggest potential impact**
   Current scientific perspectives should be gathered to arrive at a consensus view of the relative magnitude of different climate risks facing the study area. This step can be achieved either by formally creating a scientific advisory committee, or by informally consulting with individual scientists working in the field. In either case, the group of scientists should include local and global researchers with bottom-up research focused on current and future climate change-sensitive risks across the country to qualitatively identify the most relevant local hazards.

   The risks considered should include specific "event hazards" (for example, storm damage from wind or flooding, snowmelt-induced flooding, drought and heat waves) as well as "gradual shift hazards" (for example, flooding and salinization due to sea level rise and climate zone shifts). This short taxonomy forms the basic scope for hazard assessment by the expert panel.

3. **Document historical data on frequency and severity of specific events**
   In many settings, both quantitative measurements and qualitative survey-based data are available to create an assessment profile on historical severity and frequency for each hazard (for example, the historical return period of a storm surge of two meters). In the case of gradual shifts, local estimates of sea level rise and adjustments to general circulation models would provide the basic inputs.

4. **Identify areas most at risk from chosen hazards**
   This step focuses the analysis on specific areas within the country that are particularly susceptible to the selected climate hazard selected. This step is critical in deciding how to allocate limited resources. Susceptibility is based on the intersection of localized severity of the hazard and the distribution of people and assets. Two possible approaches to quantifying this vulnerability are:

   - Use existing evidence of the spatial distribution of the hazard to identify areas most at risk. This option is preferred if spatially

distributed loss data is available from insurance, academic or government sources (for example, the Foresight Flood and Coastal Defence Project in the United Kingdom).

- Approximate, in the absence of data, by overlaying the spatial distribution of the hazard (i.e., the location of various severity levels of a flood) with population density, the distribution of vulnerable populations, and the distribution of economic activity in a geocoded map. This latter approach requires a broad set of data sources as well as advanced GIS software. For example, in Guyana we leveraged more than ten different data sources to assess population distribution, economic value and income density, the location of vulnerable populations, and the distribution of flood hazard height.

QUESTION 2: WHAT IS THE MAGNITUDE OF THE EXPECTED LOSS?

The magnitude of expected loss in the area most at risk is calculated in three steps: Exhibit 4 provides an overview of the calculation. The expected loss at a future date is driven by current climate risk (or lack of adaptation to current climate), asset growth, and future change in climate risk. As discussed before, the methodology assumes that no self-adaptation will occur for the purposes of the baseline scenario, although in reality self-adaptation is likely. The magnitude of the hazard, the value of assets at risk from the hazard, and finally the vulnerability of those assets to the hazard are assessed in order to calculate the expected loss over time. To size risk, the methodology follows the insurance industry's natural catastrophe model approach, which is directly applicable to future climate-sensitive risks.

1. Hazard assessment: develop climate change-driven scenarios for frequency and severity of the selected hazard
   Future climate scenarios should be developed in consultation with expert scientists in the field, and set within a timeframe relevant to the hazards. These scenarios are then translated into changes in the expected frequency and severity of climate hazards.

   A. Develop plausible future climate scenarios. Significant uncertainty remains on how climate patterns such as temperature and precipitation will change in the future. In particular, while consensus is building on global trends in greenhouse gas emissions and the associated implications for precipitation and temperature, local predictions are often less certain. Scenarios assist, therefore, in addressing the largest uncertainty in the sequence of analyses by conservatively assessing "today's climate", "moderate climate change", and "high climate change". (See Box: Uncertainty and randomness.)

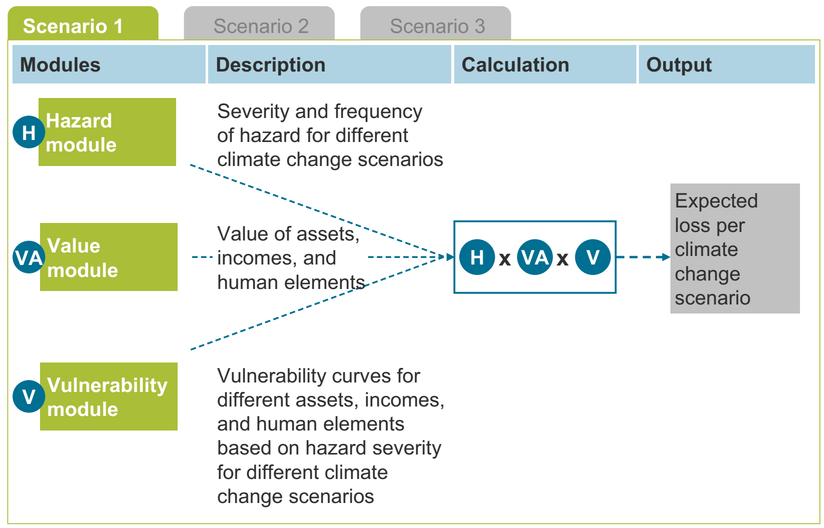
To arrive at these scenarios, a range of global and regional circulation models (GCMs and RCMs, respectively) can be used to assess changes in precipitation and temperature based on the IPCC's A1B and A2 emission scenarios. (See Box: The IPCC scenarios.)

The "today's climate" scenario assumes that future climate is the same as the current, with no climate change. The other two scenarios assume varying levels of climate change, and are defined by long-term, published models (such as GCMs) rather than the latest – often more dramatic, but less widely accepted – forecasts. We should note that in the test cases, where we diverged from the IPCC's Fourth Assessment Report we also used widely known and debated studies, for example on sea level rise[54]. Therefore, even the "high climate change" scenario for the test cases may be considered a conservative estimate by some. Decision-makers do, of course, have the option of constructing a further "extreme" scenario to gauge the risk from less widely accepted forecasts of climate change.

A note on human adaptability. Human history is full of examples of self-adaptation to natural risks. Climate change undoubtedly poses additional challenges for this inherent survival skill, but we can assume that, even without an explicit national or local adaptation strategy, people will develop their own adaptation strategies and so avoid some of the future climate risk. However, this effect was consciously ignored in the scenarios developed for the test cases. In fact, these scenarios should be rather viewed as a technical tool – a reference point to determine the potential benefit for the identified adaptation measures – rather than a prediction of the expected damage if no adaptation strategy is developed. ➔

04

Three assessments used to quantify expected losses for each scenario



UNCERTAINTY AND RANDOMNESS

In the majority of the test cases profiled in this report deterministic models were used to estimate expected loss. In Florida, in Samoa, and in the UK, however, we were able to use stochastic models – that is, models that incorporate a random element to future potential weather events. The models used in Florida and in the UK had already been developed from an extensive historical dataset by SwissRe. (See Box: Swiss Re event set for tropical cyclones in the North Atlantic[55]) Conversely, the stochastic model used in the Samoa test case was developed explicitly for this project by making use of all available historical information (for example, tide gauge records). Although deterministic models may not produce outcomes that reflect all of the uncertainties of future climate risks, they are relatively easy to customize to a set of local conditions, and are thus both feasible and practical in situations where a large body of historical climate data is not available.

B. Choose timeframe of climate data relevant to hazard. For those hazards that are dependent on precipitation, the timeframe is especially important. Because GCMs and RCMs predict future precipitation for each month, the analysis can be focused on the most relevant months for each region (for example, agricultural growing season). The Guyana test case, for instance, used monthly rainfall as a driver of urban fresh-water flooding, whereas the Maharashtra, India case focused on seasonal monsoon rainfall.

C. Model drivers of hazards. In this step, the severity and frequency of the selected hazard should be linked to precipitation, temperature, and sea level. For example, flooding severity is determined by a complex system including human intervention and physical characteristics of hydrology. However, in many cases a physical model for these many inputs may not yet exist, so assumptions and analogies must be used. For example, in Guyana, the test case assumed that rainfall correlates linearly with height of floods, which is borne out by historical evidence and the urban context. The assumptions used in this step should be verified with scientific and engineering experts.

D. Link climate change scenarios and hazard models to quantify the frequency and severity of the hazard. This step involves drawing together the model developed in step C as well as the new expected climate parameters (for example, rainfall and temperature) in each of the three climate change scenarios developed in step A. From these inputs, a correlation emerges between the severity (for example, height of flood) and frequency of the hazard event.

Existing historical data and natural hazard models can be leveraged where possible because they use probabilistic loss simulations (for example, Monte Carlo simulations) to arrive at probability distributions of event frequencies and severities. For example, Swiss Re provided detailed modeling capability when data and models were available. (See Box: Swiss Re event set for tropical cyclones in the North Atlantic.)

A vulnerability curve shows the correlation between event severity with asset loss, where asset loss is presented as a proportion of total asset value. Event severities are specified by different metrics (for example, height for flood, wind speed for storms)

However, in the absence of such models, the frequency and severity of the hazard can be estimated statically based on historical trends and expert scientific input. Expected severities for events with standard return periods (for example, 1-in-10, 25, 50, and 100-year events) can be extrapolated to arrive at expected severities, and expected losses, relating to other events.

2. Distribution of asset value: estimate size and location of future "assets" of economic and human value
   Because the impact of the hazard changes spatially, it is important to also distribute the value of assets spatially. Note, we use "assets" here to mean physical asset values. However, a holistic assessment of the value at risk from climate change should include human lives, socioeconomic factors such as health, and ecosystem degradation – in addition to physical asset valuation. Each of these areas impacted by climate change can be valued using the same method described here – a natural catastrophe modeling approach. ➔

THE IPCC SCENARIOS

In each test case assessment, a single IPCC emission and GHG concentration pathway was selected – either the A2 or the A1B emission scenario, depending on data availability. (Greenhouse gas concentration in the 2030 timeframe is similar across these two scenarios, make the test case findings comparable.) This selection allowed the scenarios could be focused on the uncertainty around temperature and precipitation changes, rather than considering different emission and concentration pathways.

Public academic research can be leveraged where necessary, as in several of the test cases, to flesh out the complex interactions between climate change and potential impacts (for example, between hurricanes and crop yield). Because the scientific foundation is public, it is relatively easy to update as information improves and scientific consensus evolves. This approach can be made even more rigorous if, at the national scale, a committee of academics were charged with developing a consensus range of scenarios.

In the test cases, both glocal circulation models (GCMs) and regional circulation models (RCMs) were incorporated in the climate change scenarios to help ensure that the scenarios were both locally relevant and globally recognizable. GCMs, while of lower geographical resolution than RCMs, have the following advantages: they are widely available through public sources; they provide directional evidence for regional climate changes; they are more widely accepted by the scientific community; and they are referenced by the IPCC. GCMs were therefore used in most of the test cases. In some cases where more research was available, and a higher level of spatial granularity desired, we included RCMs. For example, the Tanzania test case, drew on the University of Cape Town's set of RCMs, and found that they differed from the GCM results because they were able to accommodate more local phenomena: while the GCMs indicated an overall increase in rain for Tanzania due to more frequent storms along the coast, the RCMs projected a future decrease in rainfall for Tanzania's central region. Given that this region is home to subsistence and vulnerable communities as well as hydropower dams, this is an important finding. The level of granularity offered by RCMs – where available – is therefore helpful in understanding the regional differences within a country. The China test case also used an RCM, because it is widely accepted in China and had been calibrated to specific data on China, allowing a more rapid understanding of differences between north and northeast China.

A. Define asset types. In a majority of the test cases profiled in this report, we primarily assessed residential, commercial, industrial and public physical assets. Although economic loss due to damage of physical assets is certainly an important driver of total climate hazard, when implementing the methodology at a national scale, a broader range of potential valuable assets should be defined (for example, including human health).

B. Determine value and distribution of assets. In many cases, data on the value of assets exists and includes incomes as well as physical assets. Spatial distribution is very important. For example, the Samoa test case made use of GIS – a highly granular dataset covering single buildings and road networks. Where data is limited, asset values can be estimated from other sources including records of recent public investments, historical crop yields, and disease mortality rates. The spatial distribution of these assets can then be estimated, for example using population density as a proxy. In all cases, a variety of sources – and strong local engagement for verification – is required to estimate the value and distribution of assets. When projecting the likely value of assets into the future for the test cases, we assumed exogenous GDP growth based on the best available estimates in each location, such as Moody's in the United States. These top-down estimates do not inherently include climate risks in their models. So, as discussed above, they do not take into account possible feedbacks between the implementation of adaptation measures and GDP growth.

3. Vulnerability assessment: create vulnerability curves relating value at risk to events of different severities
This third step marries hazard risk with asset value. The result of this step is a set of vulnerability curves that plot the percentage of value damaged by hazards of different severity (Exhibit 6).

A vulnerability curve shows the correlation between event severity with asset loss, where asset loss is presented as a proportion of total asset value. Event severities are specified by different metrics (for example, height for flood, wind speed for storms) and assessed in earlier steps of the methodology.

USING EXPECTED LOSS ESTIMATES

Annual expected loss is a statistic that provides a sense of the magnitude of climate hazard impacts. An annual expected loss figure is powerful in that it allows a decision maker to compare accumulated losses across multiple timeframes – for example, to determine how much damage is expected to increase between now and some point in the future – as well as compare loss from climate hazards to those from other risks. Thus, it grants decision-makers with a sense of the scale of potential damages.

Natural catastrophe modeling techniques can be applied to assess the severity and frequency of a continuum of climate-related events to arrive at an estimate of total losses. This approach can also be applied to gauge the impacy of gradual climate impacts, such as sea level rise and climate zone shifts. Average expected loss is not predictive – under no circumstances should it be interpreted as a forecast for the actual loss expected in a given year. Nonetheless, quantifying the problem often drives action.

Different categories of assets typically have different vulnerability curves (for example, agriculture may be quite different from residential property in its vulnerability to a one-meter flood). Similarly, within a single asset category, these curves are highly sensitive to local parameters such as materials used in construction or crop type.

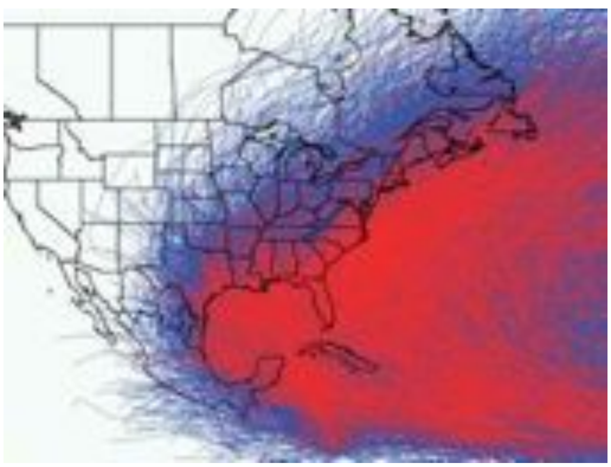
In areas where insurance is common, these curves may already exist in a useable form (for example, based on past flood damage to houses or crops). In other areas, vulnerability curves can be created by calibrating to losses from known events based on event severity, asset base at risk, and shape of vulnerability curve for similar situations (for example, flooding only, in flat areas only, and so on).

In the test cases, the expected annual loss in assets and income was associated to annual gross domestic product (GDP) to calculate loss as a percentage of GDP. Note that these cases did not attempt to model GDP, but rather took external projections and used this ratio as a proxy for the extent of damage to facilitate comparisons. This statistic necessarily provides a conservative estimate of economic impact because it does not include secondary or tertiary reactions to catastrophic events. (See Box: Using expected loss estimates.)➔

SWISS RE EVENT SET FOR TROPICAL HURRICANES IN THE NORTH ATLANTIC[55]

05

The validated event set for exposure to hurricanes in the Caribbean/North American region



Historical (red) and derived probabilistic "daughter" cyclone tracks (blue) in the North Atlantic

To produce the probabilistic Swiss Re event set, cyclone activity covering a period of 50,000 years is simulated on the basis of statistical data and the dynamic development of tropical cyclones that have occurred in the North Atlantic over the past hundred years. This simulation produces cyclone tracks that may have never occurred in reality but may occur in the future.

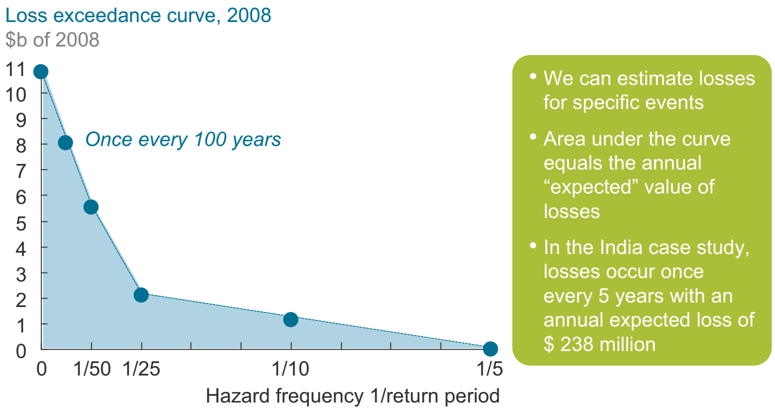
The first step in generating the event set is to vary and store the paths of the historical cyclones using a directed random walk – a mathematical simulation process based on random numbers (Monte Carlo process). Both statistical and physical factors are taken into account to determine the build-up of atmospheric pressure and the subsequent intensification and decay of the cyclones. The life cycle of the cyclone as well as meteorological data on all historical cyclones are considered here. This step defines the storm paths and the pressure developments of the probabilistic cyclones. The next step involves simulating the surface wind speeds, which are crucial in determining the extent of the damage incurred. The strength of these wind fields is calculated by applying differential equations to meteorological data. Detailed surface and topographical information is also taken into account. Making allowance for the total life span of the cyclones ensures that the hazard correlation between different regions (for example, the frequency with which a cyclone that strikes Cuba will also strike Florida) is simulated accurately. A so-called annual occurrence set is produced by randomly distributing the probabilistic event set across virtual model years.

A comparison of simulated and historical climate data (for example, frequency of various wind speeds) can test the validity of the artificially generated event set. When producing an annual occurrence set, it must be ensured that the distribution of probabilistic cyclones into Saffir-Simpson Intensity Scale categories and the cyclones' landfall characteristics correspond to historical records and/or the laws of physics. The validated event set – based on the latest scientific research – gives a reliable picture of exposure to cyclones in the Caribbean/North American region (Exhibit 5).

Expected losses calculated based on probability of occurrence

06

INDIA CASE STUDY
ILLUSTRATIVE



QUESTION 3:
HOW COULD WE RESPOND?

To answer this question, the methodology follows four steps.

1. Identify potential adaptation measures. To address each hazard in the specific location, the range of potential adaptation measures is identified that could potentially reduce the impact of the hazard. Identifying a full range of measures provides options to mitigate and prevent risk, as well as transfer risk. Measures can be considered in four categories: (a) infrastructure or asset based; (b) technology or process; (c) systemic or behavior – all risk mitigation or prevention measures; and, (d) financial responses – including risk transfer. When drafting a list of measures, it is helpful to consult as many other categorizations of adaptation measures as possible (for example, the UNDP policy framework), and to consider measures that act to minimize damage from both severe and less severe events. The purpose of this step is to identify a broad range of potential alternatives and not yet to assess the effectiveness of particular measures.

   In the test cases, we focused on assessing measures known and executable today, so future innovations in technology were not assessed. This choice has the benefit of making the measures much more tangible to decision-makers, but the results of the analysis must be presented so that future developments (for example, cultivation of new seed types to improve crop yield) can be incorporated. Correspondingly, the analyses should be repeated periodically (for example, every five years), to incorporate new innovations in adaptation.

2. Determine overall feasibility and applicability of potential measures. In this step, the long list developed in step 1 is screened against basic feasibility criteria including technology, engineering, local setting, and cultural constraints. This assessment is qualitative in nature but should be informed by interviews with local experts as well as published performance of these measures against current climate hazards.

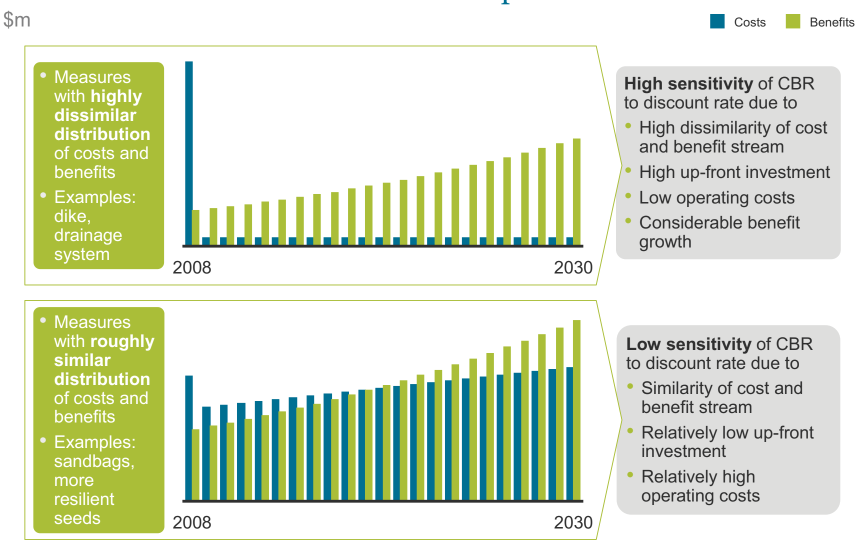
   In the test cases, we chose a subset of measures to calculate costs and benefits. Adaptation measures are wide-ranging[57] and infinitely variable. For example, a dike against coastal flooding could be built one meter high, two meters high, and so on. For each hazard, we assessed a range of alternatives based on literature reviews as well as interviews and local assessments with government, academics and NGO stakeholders, but did not attempt to exhaustively evaluate all potential combinations of parameters for each measure.

3. Calculate societal costs. Each measure that passes the basic feasibility screening is then assessed quantitatively using a net present value approach, as follows:

   - Determine the discount rate, based on local government infrastructure decision discount rates where possible, or on the expected rate of return for the "next best" investment. The discount rate assists decision-makers in directly comparing and evaluating alternative investment options – adaptation oriented measures as well as other investments that the same resource would be allocated. In the test cases, we chose locally relevant discount rates to calculate cost-benefit ratios. A large body of research on the appropriate discount rate on societal long-term decisions exists[58]. For decisions with long timeframes of around 100 years, high discount rates can undervalue needs of future generations and therefore a

07

A measure's cost-benefit ratio is less sensitive to the discount rate when most of the investment is upfront



SOURCE: ECA analysis

socio-economic discount rate, similar to that discussed in the Stern Report, is appropriate. Where available, we used discount rates from government decision-makers directly, given their "next-best" rate of return on investments or standard approaches for infrastructure decisions[59]. Country-specific discount rates help provide a fair assessment of alternative investment options for public and private sectors and allow appropriate reflection of investment stage in each test case. We conducted sensitivity analysis on the discount rate in each test case and found that both the total size of the averted loss and the prioritization of measures may change significantly with discount rate. This is particularly true where measures do not involve significant upfront capital expenditures, so that the net present value of costs in later years are sensitive to the discount rate (Exhibit 7).

- Define scope of the measure by determining the maximum potential for implementing the measure in the local context. This should include the expected penetration rate (for example, what percentage of the local population is likely to take up incentives to improve their housing structures against flooding?)

- Calculate costs of each measure, including capital expenditures, operating expenditures, and operating expenditure savings. Note that the detailed cost work often requires the highest time investment of any step and demands a rigorous bottom-up approach. For example, to calculate the cost of building rainwater catchments on homes, the cost of roofing upgrades, storage tank materials, hourly wages, and estimated maintenance must be tailored to the specific environment and economy. Also required is the expected lifetime of each measure and its terminal value if the lifetime of the measure is longer than the period being considered.

In the test cases, we extrapolated future costs from today's costs based on locally verified estimates and assume cost trajectory growth based on inflation (for example, if inflation is 3 percent, the cost of quarried rock to build seawall will increase at 3 percent annually). Note that this excludes changes in availability or price (for example, the depletion of quarries needed to produce rock to build seawalls, or the introduction of competition resulting in lower prices)

4. Calculate expected loss averted for each measure. In the context of the cost-benefit curve, "benefit" is defined as loss averted and any additional revenue streams created by a measure (if applicable). Loss averted is calculated by running the expected loss model after assuming the new measure is incorporated.

   Measures can act to avert loss through any of the three components of the expected loss calculation model, as described below:

   - Hazard: acted on by measures that reduce the physical severity of hazards (for example, improvement of drainage systems will increase drainage capacity, resulting in less severe flooding for a storm of a certain severity)

   - Assets at risk: acted on by measures that reduce the total value of assets exposed to climate hazards (for example, relocation of agriculture or population centers to an area less prone to drought) →

READING THE COST CURVE

The width of each bar in a cost curve represents the cumulative potential of that measure to reduce total expected loss up to 2030 for a given scenario. This value assumes an optimal scale of implementation of the measure – that is, if the maximum potential penetration is estimated at 75 percent, the loss averted by the measure will assume 75 percent penetration. Note that the width of the bar is therefore an approximation, and may not reflect the actual loss averted if the measure were to be implemented.

The height of each bar represents the ratio between costs and benefits for that measure. The costs and benefits used to calculate the ratio are in 2008 real dollars. Whether or not this ratio is attractive to a decision maker depends on many factors, including risk appetite. After considering the other – including non-economic – impacts and benefits related to implementing a measure, a risk-neutral decision maker would select measures based on a sense of how much protection they offer and at what cost. The advantage of calculating cost-benefit ratios for all measures is that doing so allows decision-makers to compare measures using a single simple metric.

Assessing the cost and damage aversion potential of each measure can be quite difficult. The potential loss aversion is particularly uncertain, even for measures for which extensive research exists – for example, for building codes to fix roofs against hurricane winds. On the cost side, we have minimized uncertainties in the test cases by looking only at measures that had already been developed and tested. However, while we verified costs locally using bottom-up estimates, the cost figures for the test cases are just that – estimates – and incorporate a set of assumptions. These estimated costs did not consider taxes or other private actor costs, so the figures in the cost curve cannot be used to determine individual economics.

The assembled cost curve shows – from left to right – the range of measures from least cost-efficient to most cost-efficient. We should note that the purpose of test cases described in this report was to apply and test a consistent methodology across sectors, rather than to conduct specific research on any one type of measure. The results in each case should thus be used to start discussions on the different measures and the opportunity to avert expected losses, rather than be read as recommendations to implement certain measures.

- Vulnerability: acted on by measures that reduce the expected damage to assets from a given event (for example, changing building codes for residential roofs so that a severe hurricane is less likely to damage them)

Two or more measures acting on the same component of the loss model may overlap in effectiveness, so that implementing them together leads to either greater or lower loss aversion than the two would provide implemented separately. For example, building a seawall may reduce the effectiveness of sandbagging, since the seawall already serves to protect assets from the first meter or two of coastal flooding. To ensure that multiple measures are accurately assessed, it is important to incorporate the incremental benefits of each measure in addition to the existing portfolio, rather than simply adding the expected benefits from each measure linearly.

5. Create the cost-benefit curve for all measures. The cost-benefit curve is constructed with the cost-benefit ratio of each measure on the vertical axis, and the expected loss averted of each measure plotted cumulatively on the x-axis.

   In the test cases, we calculated the cost-benefit ratio for each measure based on the net present value of all cash flows (including terminal value) in 2008 currency. Together, the cost-benefit ratios for all measures provide the vertical axis of the adaptation cost curve. The cost-benefit curve can be interpreted as follows:

   - Measures with a cost-benefit ratio of more than one are not attractive based on a risk-neutral, purely economic rationale, but may be attractive for other reasons
   - Measures with a cost-benefit ratio of less than one are cost effective because the loss averted is greater than the cost invested

   - Measures with a cost-benefit ratio of less than zero are expected to not only pay for themselves with averted loss, but also generate additional economic value – these measures should be implemented regardless of climate risk. In our analyses, agriculture and energy measures often had negative cost-benefit ratios due to the societal upside from improving crop yield and energy efficiency, respectively. (See Box: Reading the cost curve.)

Note that expected loss and expected loss averted are calculated based on average annual economic loss as extrapolated from the probability of an event with a given severity occurring in one year. In reality, of course, real economic losses may vary dramatically from year to year. Expected loss and expected loss averted are therefore useful as long term indicators of the effectiveness of adaptation measures from a risk-neutral point of view. However, most people are in fact risk averse, and do not view a once-a-decade event causing $100m of damage as equivalent to an annual event causing $10m of damage. This is a limitation of the cost curve, but can be accommodated by setting the cost-benefit ratio criterion higher. For example, a risk-averse decision-maker might require that a measure pays back only 50 percent of its cost in expected loss averted, making attractive all measures with a cost-benefit ratio of less than 2. ➔

NEXT STEPS: DEVELOPING THE METHODOLOGY FURTHER

This report has highlighted several areas where this methodology can be further developed in the future, or tailored to local conditions and requirements. The methodology, and the initial set of findings it has generated to date, is a building block that can be modified, augmented, and integrated with other work on climate adaptation. For example, the quantitative analyses profiled in this report are a possible complement to NAPAs, which incorporate much of the deep local knowledge that would be critical to translating quantitative risk assessment and cost-benefit analysis into policy and implementation plans.

The next generation of integrated asset models will help improve our understanding of the impacts of climate change and therefore help assess the total global cost of adaptation. Based on numerous assumptions, general equilibrium models can help to model the complex interplay of economic choices. As is clear from the assessment of current climate risk in this study, many decision-makers already face significant risks today and need to make practical decisions in the next five years on where to focus their scarce resources – in knowledge development, planning and preparation, disaster management and insurance, or in making current development plans climate-resilient.

In the test cases, we typically selected one or two major hazards for which to conduct deep analyses. However, we believe the methodology presented here would translate well to a broad range of expected impacts across multiple hazards, based on selected applications we undertook as part of the test cases. For example, in addition to more widespread hazards like floods, droughts, and cyclones, we also applied our methodology to healthcare and the private sector energy impacts in Tanzania, to gradual climate zone shift in Mali, and to salinization in Samoa. To date the work described in this report has focused mostly on vulnerable populations. For example, in India, we focused on drought-prone subsistence farmers. In Mali, we focused on populations living at the edge of encroaching desert, which are under pressure to migrate. However, we did not attempt to be exhaustive by systematically addressing the range of livelihood issues that these populations face. A critical area for further development is to extend our basic analytical approach to evaluate the impacts of climate risk on other aspects of the economy (for example, leisure); on lives and livelihood (beyond health); on ecosystems; and at the national scale.

The methodology described above is designed to be modular and replicable across the full spectrum of economic and climate hazard settings. Each of the analytical components of this methodology may prove useful in guiding decision-makers. This methodology will aid in the prioritization of adaptation measures and optimal allocation of resources to minimize the expected loss from climate change. ❍

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APPENDICES

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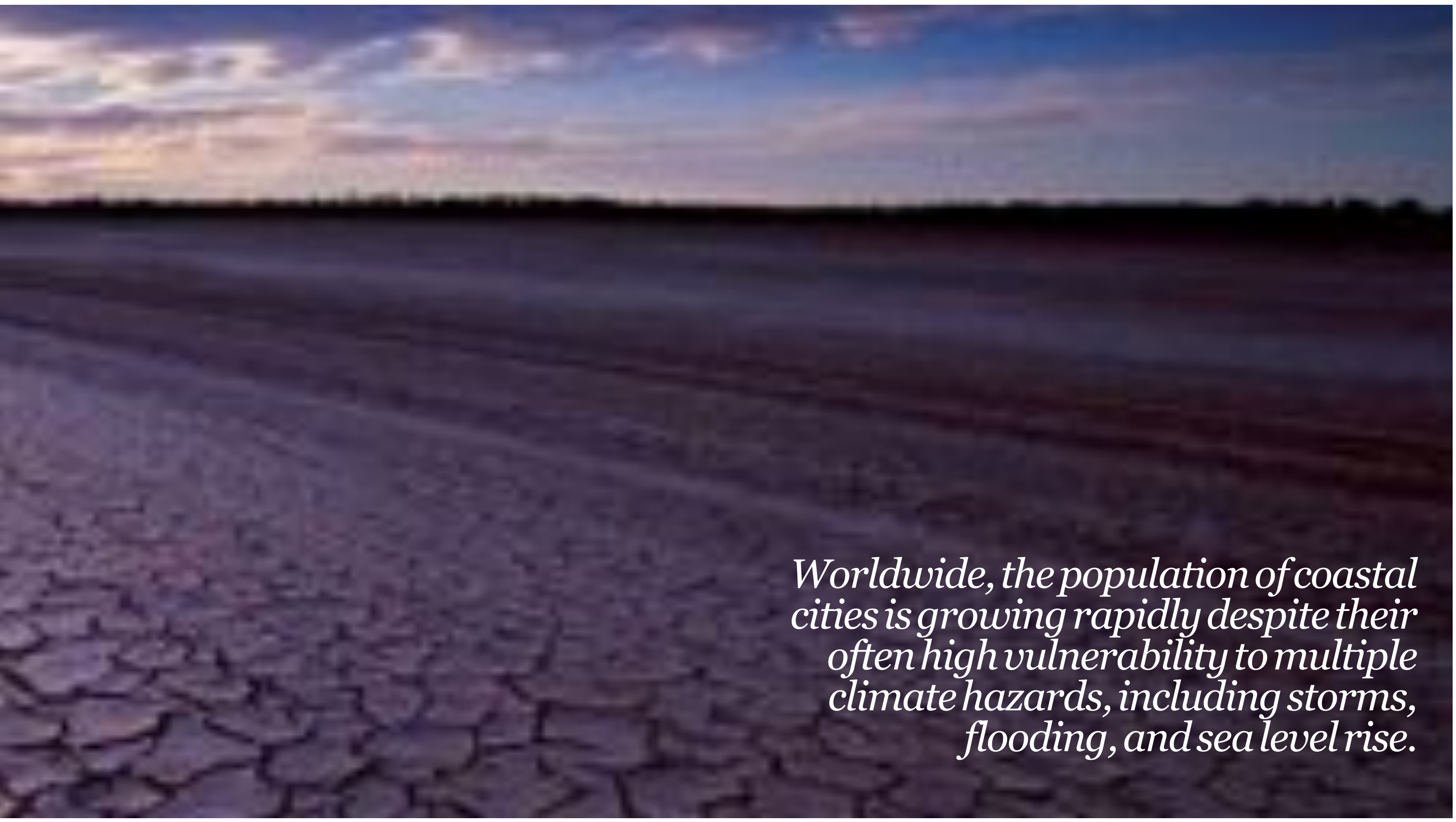
58 see Stern Report

59 Florida: 4.5% is the 5 year average of the Federal Reserve’s 20 year State and local bonds. Guyana: 7% based on interviews with Office of the President. United Kingdom: 3.5% for first 30 years based on the Treasury guidance as noted in “The Greenbook: Appraisal and Evaluation in Central Government”. India: 8% based on Planning Commission rate used for economic assessment and close to risk free rate in India. Mali: 8% based on local interviews. Tanzania: No discount rate used because measures were upfront cost focused and benefits expressed in terms of Gwh for power and number of people for health. Samoa: 4.5% based on discussions with MNRE based on assumption of continued government stability. China: 8% based on commonly used private sector WACC. Measure categores robust to sensitivity analysis of 4%. ❍


Worldwide, the population of coastal cities is growing rapidly despite their often high vulnerability to multiple climate hazards, including storms, flooding, and sea level rise.

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